Clinical, Cosmetic and Investigational Dermatology

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REVIEW

The Anti-Aging Effects of Adipose-Derived Mesenchymal Stem Cell Exosomes on Skin and Their Potential for Personalized Skincare Applications

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Abstract: Stem cell-derive exosomes have gained increasing attention in the skincare industry in recent years due to their multiple anti-aging benefits. However, differences in cell sources lead to significant heterogeneity in the composition of secreted exosomes, resulting in inconsistent biological effects. Moreover, the lack of standardized production protocols and the technical challenges associated with large-scale manufacturing continue to limit their broader application in the beauty industry. As a narrative review, this article systematically summarizes the biological functions and mechanisms of action of autologous adipose mesenchymal stem cell-derived exosomes (AMSCs-Exos) in anti-skin aging, covering in vitro, in vivo, and clinical studies. Recent studies have shown that autologous exosomes derived from AMSCs not only possess the common bioactivity shared by stem cell-derived exosomes but also exhibit higher biocompatibility and a lower risk of pathogen transmission. In addition, their suitability for small-scale production makes them a more advantageous option. Furthermore, advances in artificial intelligence (AI) technology are driving the transformation of the cosmetics industry from traditional skincare to personalized skincare: AI provides a basis for the personalized matching of exosome dosage and delivery methods through high-precision skin condition monitoring. It optimizes the iteration of customized exosome products by integrating intelligent analysis of dynamic changes in users' skin texture and usage feedback, and achieves closed-loop management from "universal formulations" to "precision repair" by combining skin physiological data with user preferences. The integration of AI with AMSCs-Exos not only expands their potential in personalized skincare applications but also holds promise for generating valuable clinical data, thereby further advancing the concept and scientific development of precision skincare.

Keywords: adipose-derived mesenchymal stem cells, exosomes, anti-skin aging, personalized skincare, customized cosmetics, artificial intelligence

Introduction

The skin is the largest organ of the human body, covering the entire surface and serving as the first line of defense.[1] As such, it is often the earliest organ to exhibit visible signs of aging. With increasing public awareness of health and aesthetics, greater attention has been devoted to understanding and managing skin aging. Skin aging is generally classified into two types: intrinsic and extrinsic. Intrinsic aging is primarily governed by physiological factors such as genetics, metabolic activity, and endocrine function. In contrast, extrinsic aging is mainly driven by environmental factors, including ultraviolet (UV) radiation, air pollution, and unhealthy lifestyle habits. Among these, UV-induced photoaging is widely recognized as the most significant contributor to extrinsic skin aging.[2,3] Aging skin undergoes distinct changes in appearance, function, and structure. These changes are characterized by a gradual decline in the activity of keratinocytes, melanocytes, and skin appendages, leading to slower keratinocyte turnover, thinning of the

Received: 17 June 2025
Accepted: 2 September 2025
Published: 12 September 2025

epidermis, and increased transepidermal water loss. In addition, melanin distribution becomes uneven, resulting in mottled pigmentation. Within the dermis, collagen fibers and elastic fibers progressively degrade and break down, contributing to wrinkle formation, reduced skin firmness, and diminished elasticity.[3,4]

Common anti-aging treatments for the skin include the use of skincare products, chemical peels, energy-based therapies (such as laser and radiofrequency), and various injectable treatments.[5] Although these methods are widely used in clinical practice and daily skincare, they all have certain limitations. For example, topical formulations struggle to penetrate the skin barrier to achieve deep repair; laser therapy may cause transient erythema or pigmentation abnormalities; and retinoids are often associated with adverse reactions like skin irritation. Furthermore, most of these methods focus on improving superficial symptoms and lack the ability to actively regenerate skin tissue. Therefore, researchers and clinicians are constantly exploring safer and more effective strategies to achieve more significant anti-aging effects. Among numerous emerging approaches, exosome therapy has attracted widespread attention in recent years as a cutting-edge and highly promising technology. With its nanoscale particle size, it can efficiently penetrate the skin barrier. Through the bioactive components it carries (such as miRNAs and growth factors), it precisely regulates cell functions, achieving multiple effects including anti-inflammation and promoting repair. Meanwhile, derived from autologous cells, it has lower immunogenicity and a reduced risk of side effects. Notably, it exhibits unparalleled advantages over traditional therapies in activating the endogenous regeneration mechanism of the skin, and has been widely applied in various cosmetic products such as facial creams, serums, and masks.[6] Exosomes are spherical extracellular vesicles ranging from approximately 40 to 160 nanometers in diameter, enclosed by a phospholipid bilayer membrane, and secreted by nearly all cell types. They are rich in proteins, nucleic acids, and lipids, and play a key role in mediating intercellular communication.[7] Notably, exosomes derived from stem cells have demonstrated exceptional bioactivity, showing great potential in delaying skin aging. Based on their self-renewal ability and differentiation potential, stem cells can be categorized into three main types: embryonic stem cells (ESCs), adult stem cells, and induced pluripotent stem cells (iPSCs). ESCs are derived from early-stage embryos and possess high pluripotency, but their application is limited by ethical concerns and a relatively high risk of tumorigenicity. iPSCs are obtained by reprogramming somatic cells through gene editing and exhibit pluripotency similar to that of ESCs, thereby partially avoiding ethical issues; however, they still carry a potential risk of tumor formation. In contrast, adult stem cells naturally exist in the tissues or organs of adult individuals, involve no ethical controversy, and are associated with a lower tumorigenic risk due to their more limited differentiation capacity.[8] Among adult stem cells, mesenchymal stem cells (MSCs) are the most extensively studied, and they can be isolated from various tissues including adipose tissue, bone marrow, perinatal tissues, dental pulp, and others.[9] MSC-derived exosomes have thus become a major focus in current anti-aging skin research. The acquisition of bone marrow-derived MSCs (BM-MSCs) is relatively invasive, potentially causing significant discomfort to patients and posing a higher risk of donor site complications.[10,11] Furthermore, with increasing donor age, the number of BM-MSCs and their proliferative and differentiation capacities decline markedly, further limiting the yield of extractable cells.[12] Although perinatal-derived MSCs exhibit high biological activity, their collection must be conducted under specific conditions, including obtaining informed consent from the mother and strictly adhering to standardized perinatal collection protocols.[13] As for dental pulp stem cells, the limited number of harvestable teeth and the fact that lost teeth are difficult to regenerate necessitate a careful evaluation of their potential benefits and associated risks before applying them in anti-aging skin treatments.[14] In contrast, adipose-derived MSCs (AMSCs) offer several advantages, including ease of acquisition, minimal donor site damage, and negligible ethical concerns. Additionally, their proliferative and differentiation potential is less affected by aging.[15,16] Therefore, AMSCs are considered the most promising and practically valuable cell source for exosome production in anti-skin aging therapies.

In recent years, the potential advantages of exosomes in combating skin aging have attracted widespread attention, with a growing body of related research and promising preliminary experimental results. However, due to insufficient clinical trial data, no exosome-related products have yet received official approval from the US Food and Drug Administration (FDA). At the same time, mainstream media and online platforms often exaggerate the efficacy of exosomes, which may mislead the public and lead to blind enthusiasm for exosome-based therapies.[17,18] To rationally assess the gap between current scientific progress and practical application, it is essential to rely on rigorous scientific evidence and explore the feasibility of implementation in depth. This review aims to systematically evaluate the

biological functions and mechanisms of exosomes derived from autologous AMSCs in the context of anti-skin aging. On this basis, we seek to explore the development of personalized skincare strategies centered on customized exosome-based products, with the goal of revolutionizing facial aesthetics and ushering in a new era of precise, safe, and effective skincare. Specifically, this article will first elaborate on the biological characteristics and preparation processes of AMSCs and their exosomes. Subsequently, it will systematically analyze their mechanisms of action and research evidence (covering in vitro, in vivo, and clinical trials) in wrinkle reduction, moisturization, pigmentation improvement, scar repair, and hair loss prevention. Then, combining the current status of commercial applications and the trend of personalized skincare, it will discuss the application potential of integrating exosomes with artificial intelligence technology. Finally, it will summarize the current challenges and prospect the future development directions.

AMSCs and Their Exosomes

Adipose tissue is widely distributed throughout the human body, with subcutaneous adipose tissue accounting for approximately 80% to 90% of total body fat, while visceral adipose tissue comprises about 10% to 20%.[19] Based on functional and morphological characteristics, adipose tissue can be categorized into three types: white adipose tissue, beige adipose tissue, and brown adipose tissue. AMSCs are primarily isolated from sub-cutaneous white adipose tissue. AMSCs exhibit typical characteristics of MSCs, including adherence to plastic surfaces in standard culture conditions, a specific surface marker expression profile (positive for CD73, CD90, and CD105, and negative for CD45, CD34, and CD14), and multipotent differentiation potential into osteoblasts, adipocytes, and chondrocytes.[20] Notably, AMSCs express low levels of MHC class I and lack expression of MHC class II molecules, granting them relative immunoprivileged properties.[21] Adipose tissue is commonly harvested via liposuction or fat biopsy. Among these, fat biopsy is less invasive due to the smaller volume of tissue extracted, making it more suitable for applications such as customized cosmetics.[22] Following tissue collection, enzymatic or non-enzymatic (mechanical) methods are used to process the adipose tissue, followed by centrifugation to isolate the stromal vascular fraction, from which AMSCs, a population of fibroblast-like cells, are subsequently derived.[23] In enzymatic isolation, collagenase is typically used to degrade the extracellular matrix (ECM) of adipose tissue, thereby releasing embedded AMSCs. The target cells are then obtained via centrifugation. In contrast, mechanical methods rely on physical disruption to sepa-rate the cells. Studies have shown that enzymatic methods yield approximately 2.3×10^5 to 18.0×10^5 cells per milliliter of adipose tissue, whereas mechanical methods yield between 0.03×10^5 and 26.7×10^5 cells per milliliter. In terms of processing time, enzymatic methods require 50 to 210 minutes, while mechanical methods take only 8 to 20 minutes.[24] In summary, enzymatic methods offer higher cell yield and viability but are associated with higher costs and longer processing times. Mechanical methods, although yield-ing fewer and less viable cells, are simpler, faster, and more cost-effective. More importantly, the use of xenogeneic collagenase in enzymatic methods is subject to regulatory restrictions, whereas mechanical methods are more compliant with current regulations, making them more favorable for clinical and cosmetic applications.[25] It is worth noting that there are significant differences between AMSC therapy and AMSCs-Exos therapy, and the unique properties of exosomes make them an important alternative or auxiliary approach to cell therapy.[21,26,27] MSC therapy relies on the direct transplantation of living cells, and its efficacy may involve multiple mechanisms such as cell colonization, differentiation, and paracrine effects.[9,26] However, it has obvious limitations: allogeneic cell transplantation may trigger immune rejection;[2,21] cell survival efficiency is greatly affected by the local microenvironment;[24,25] strict temperature control is required during transportation and storage to maintain cell viability;[28–30] and there is also a potential tumorigenic risk.[8,27] In contrast, as nanovesicles secreted by cells, exosomes do not have a complete cellular structure and mediate intercellular communication only through the bioactive substances they carry (such as proteins, nucleic acids, lipids, etc).[7,26,31] Their advantages are prominently reflected in the following aspects: significantly lower immunogenicity (due to low expression of MHC molecules),[21,26] eliminating the need to consider cell survival;[28,29] easier achievement of long-term stable storage and convenient transportation through technologies such as lyophilization and cryopreservation;[28–30] and complete avoidance of the tumorigenic risk that may be caused by cell transplantation.[27] Therefore, exosomes can not only serve as an alternative to stem cell therapy (by simulating its core paracrine effects)[26,32] but also act as an auxiliary means (used in combination with cell therapy to enhance efficacy and reduce safety risks).[33]

Exosome biogenesis is initiated by the inward invagination of the plasma membrane to form early endosomes, which further mature into multivesicular bodies (MVBs). When MVBs fuse with the plasma membrane, their internal vesicles are released into the extracellular space as exosomes.[31] Exosomes derived from AMSCs (AMSCs-Exos) mediate intercellular communication by delivering proteins, nucleic acids, and lipids originating from their parent AMSCs. AMSCs-Exos are highly stable, effectively protecting their cargo from degradation and exhibiting low tumorigenicity. Moreover, due to their low expression of MHC class I molecules and lack of MHC class II molecules, they are less likely to trigger immune rejection.[26,27]

Zhang et al and Ni et al conducted MicroRNA (miRNA) expression profiling and proteomic analyses of exosomes derived from AMSCs-Exos, identifying 148 miRNAs and 1,466 proteins, respectively.[34,35] Studies by Zhu et al and Yang et al demonstrated that AMSCs-Exos carry a variety of angiogenesis-related miRNAs, such as miR-126, miR-130a, and miR-132. These miRNAs enhance angiogenic capacity by promoting the expression of vascular endothelial growth factor (VEGF) and fibroblast growth factor (FGF) in endothelial cells.[36,37] Moreover, Bucan et al[38] found that AMSCs-Exos contain multiple neuroregenerative factors, including brain-derived neurotrophic factor, insulin-like growth factor-1, nerve growth factor, acidic FGF, and glial cell line-derived neurotrophic factor. These factors significantly promote neurite outgrowth in dorsal root ganglion neurons. In addition, AMSCs-Exos are enriched with neprilysin, an enzyme with potential therapeutic relevance for Alzheimer's disease, which degrades amyloid β peptides.[39]

The standardization of exosome isolation methods has become a critical issue in current research. Commonly used isolation techniques include ultracentrifugation, ultrafiltration, immunoaffinity capture, and polymer-based precipitation. Among these, ultracentrifugation is still widely regarded as the "gold standard" for exosome isolation. Its main advantage lies in enabling large-scale exosome extraction; however, it also presents several limitations, such as being time-consuming, relatively low in purity, and associated with high operational costs. Ultrafiltration employs membranes with specific pore sizes or molecular weight cut-off values to achieve size-selective separation of particles. This method offers the benefit of significantly reducing processing time and does not require expensive or complex equipment. Nevertheless, membrane clogging remains a major limitation. To address this issue, researchers have introduced tangential flow filtration (TFF), a technique in which fluid flows parallel to the membrane surface. TFF effectively minimizes membrane clogging and significantly enhances the purity, yield, and biological activity of the isolated exosomes.[28] The ExoSCRT™ technology employed by Cho et al is based on the TFF principle. Using this technique, exosomes derived from AMSCs-Exos have been successfully isolated and officially listed in the International Cosmetic Ingredient Dictionary. Furthermore, toxicological tests conducted under Good Laboratory Practice conditions confirmed the safety of these exosomes.[32] Therefore, the application of this technology in the production of customized cosmetics is not only feasible but also provides strong support for clinical translation and market promotion of the products.

After the isolation of exosomes is completed, transmission electron microscopy (TEM) is commonly used to observe their morphological characteristics, nanoparticle tracking analysis (NTA) is employed to measure the distribution of particle sizes, and Western blot is performed to detect typical tetraspanin markers on the plasma membrane (such as CD9, CD63, and CD81), in order to comprehensively determine whether the extracted components are exosomes[28] (Figure 1).

To facilitate transportation and widespread clinical application, maintaining the biological activity of exosomes during storage is particularly crucial. Among various storage conditions, temperature is considered the most critical factor affecting exosome bioactivity. Common preservation methods include cryopreservation, lyophilization, and spray drying. Studies have shown that among 4°C, −20°C, and −80°C conditions, −80°C is the most ideal storage temperature when combined with the use of trehalose as a cryoprotectant. However, compared to freshly isolated exosomes, noticeable morphological changes can be observed even after just 4 days of storage at −80°C, and by 28 days, a significant decline in biological activity is evident, likely due to the leakage of internal contents. Therefore, using freshly prepared exosomes for product development not only better preserves their functional integrity but also makes them more suitable for applications such as customized cosmetics with high added value.[28–30]

The Role of AMSCs-Exos in Anti-Skin Aging

Although aging affects all organs of the body, the earliest and most noticeable changes usually appear in the skin, which is largely associated with environmental factors, particularly UV radiation-induced photoaging.[40] Both intrinsic and

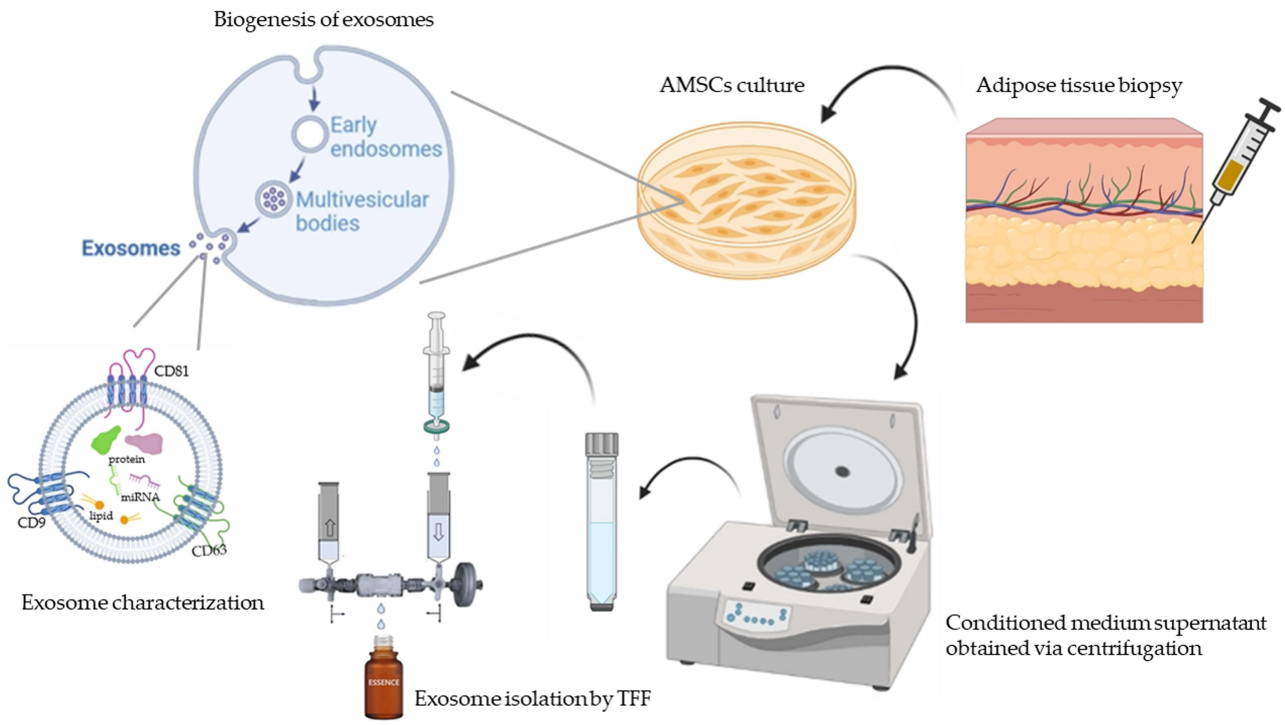

Figure 1 Schematic overview of AMSCs-Exos harvesting process. The figure was generated with BioRender.

extrinsic factors that contribute to skin aging can induce the production of reactive oxygen species (ROS), thereby triggering oxidative stress and accelerating the aging process. Oxidative stress leads to a gradual decline in the proliferative capacity of keratinocytes and fibroblasts, weakens the skin's natural barrier function, and increases transepidermal water loss, resulting in skin dryness. Meanwhile, the decreased synthesis of collagen and elastin promotes wrinkle formation and reduces skin elasticity; in addition, abnormal activation of melanogenesis-related enzymes causes hyperpigmentation.[41] In recent years, studies have shown that AMSCs-Exos exhibit significant potential in maintaining skin health, effectively delaying and even partially reversing the aging process of the skin (Figure 2 and Table 1).

Anti-Wrinkle

Structural proteins in the dermis, mainly collagen and elastin, are primarily synthesized by fibroblasts. During photoaging, oxidative stress not only inhibits the proliferative capacity of fibroblasts but also activates the expression and activity of matrix metalloproteinases, leading to increased degradation and decreased synthesis of structural proteins, thereby promoting wrinkle formation and reducing skin elasticity.[70]

In in vivo models of UV-induced photoaging in rats and mice, intradermal injection of AMSCs-Exos resulted in a marked increase in dermal thickness, enhanced collagen synthesis, and decreased expression of matrix metalloproteinases (MMPs). These findings suggest that AMSCs-Exos possess promising anti-wrinkle effects and anti-photoaging potential.[42–45] Moreover, a 12-week prospective, randomized, split-face clinical study involving 28 volunteers with facial wrinkles was conducted to evaluate the clinical efficacy of combining human AMSCs-Exos with microneedling for facial skin aging. The results showed that, compared to the control side, the treated side exhibited significant improvements in wrinkle reduction and skin elasticity, which were further confirmed through histopathological analysis.[46] Gao et al demonstrated that in an in vitro photoaging model established using UV-irradiated human dermal fibroblasts, intracellular ROS accumulated significantly. AMSCs-Exos effectively scavenged excess ROS by activating the Nrf2 signaling pathway. Moreover, AMSCs-Exos enhanced collagen synthesis via upregulation of the transforming growth factor-β (TGF-β)/Smad signaling pathway and suppressed MMPs expression by inhibiting the MAPK/AP-1 pathway, thereby reducing collagen degradation and exhibiting notable anti-photoaging effects.[47] To further elucidate the key bioactive

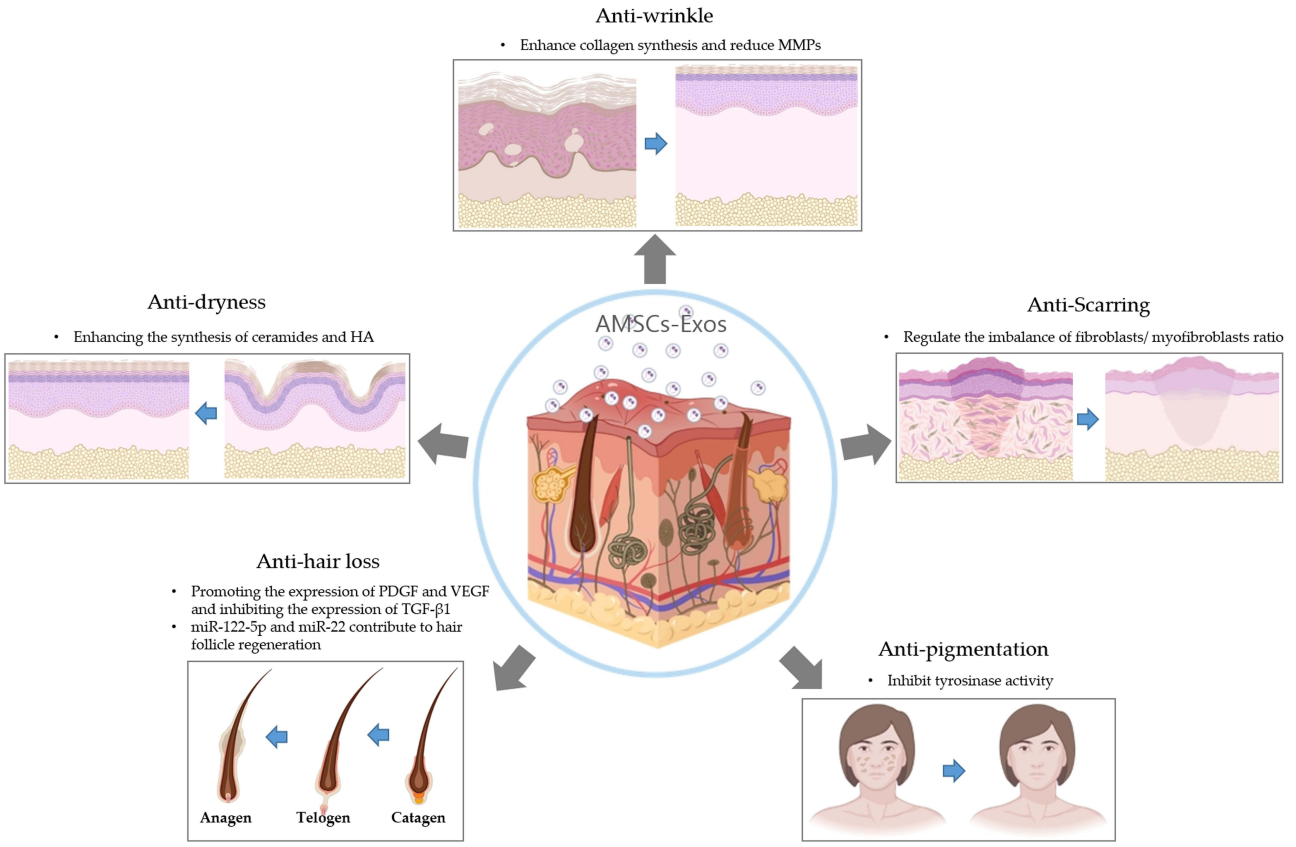

Figure 2 The role of AMSCs-Exos in skincare during the skin aging process. The figure was generated with BioRender.

component responsible for these effects, Gao et al generated miR-1246-overexpressing AMSCs-Exos and assessed their anti-photoaging and anti-wrinkle efficacy in both the aforementioned in vitro model and a UV-induced photoaging mouse model. The results revealed that miR-1246 primarily exerted its anti-photoaging function in vitro through the previously described signaling pathways. In vivo, it significantly reduced wrinkle formation by inhibiting collagen degradation. Collectively, these findings identify miR-1246 as the critical functional component of AMSCs-Exos responsible for mitigating UV-induced skin photoaging.[71]

Anti-Dryness

As the outermost layer of the epidermis, the stratum corneum plays a critical role in regulating skin hydration and maintaining barrier function. Filaggrin within corneocytes can be enzymatically degraded into natural moisturizing factors (NMFs), which enhance skin hydration and thereby achieve moisturizing effects. The structural integrity of the skin barrier depends on the lipid bilayers distributed between corneocytes, primarily composed of ceramides, cholesterol, and free fatty acids. These components effectively prevent transepidermal water loss and help maintain skin moisture balance.[72,73] However, photoaging disrupts this barrier structure and inhibits the production of NMFs, ultimately leading to increased transepidermal water loss and skin dryness.[73]

AMSCs-Exos effectively suppress excessive inflammatory responses by inducing macrophage polarization toward the M2 phenotype. Simultaneously, they promote the proliferation and differentiation of keratinocytes, enhance collagen deposition and epithelialization of the skin, and further facilitate angiogenesis. By accelerating the wound healing process, AMSCs-Exos contribute to the repair and functional restoration of damaged skin barriers, thereby demonstrating significant therapeutic potential in skin regeneration and repair.[48–50] Zhang et al reported that AMSCs-Exos promote skin barrier repair by upregulating the expression of growth factors such as basic FGF (bFGF) and TGF-β, which in turn activate the PI3K/Akt signaling pathway.[51] In a mouse model of skin barrier injury, Shin et al further confirmed that

Table 1 Applications of AMSCs-Exos in Anti-Skin Aging

Categories of Anti-Aging Effects	Study Type	Findings	Ref.
Anti-wrinkle and photoaging repair	In vivo study;[42–44] In vitro study[45]	It can significantly increase the thickness of the dermis, promote collagen synthesis, and reduce the expression levels of MMPs.	Liang JX et al, 2020;[42] Cao Z et al, 2021;[43] Choi JS et al, 2019;[45] Xu P et al, 2020[44]
	A prospective randomised single-blinded clinical trial	Twenty-eight volunteers participated in the study. The reduction in wrinkles and improvement in skin elasticity were more significant, and this result was further confirmed by histopathological analysis.	Park GH et al, 2023[46]
	In vitro study	MiR-1246 in AMSCs-Exos can effectively eliminate excessive ROS by activating the Nrf2 signaling pathway; meanwhile, it enhances collagen synthesis by upregulating TGF-β/Smad signaling pathway, and downregulates the expression of MMPs by inhibiting the MAPK/AP-1 pathway, thereby reducing collagen degradation.	Gao W et al, 2021[47]
Skin barrier restoration and moisturization	In vitro study and In vivo study	By inducing the polarization of macrophages toward the M2 phenotype, excessive inflammatory responses can be effectively inhibited; meanwhile, it can promote the proliferation and differentiation of keratinocytes, enhance skin collagen deposition and epithelialization processes, thereby facilitating the repair and functional recovery of the damaged skin barrier.	Wang Y et al, 2025;[48] Wang Y et al, 2023;[49] Song Y et al, 2023[50]
	In vitro study and In vivo study	By upregulating the expression of growth factors such as bFGF and TGF-β, it activates the PI3K/Akt signaling pathway, thereby promoting the repair of the skin barrier.	Zhang W et al, 2018[51]
	In vivo study	It can promote the synthesis of ceramides, reduce the levels of pro-inflammatory cytokines, and significantly decrease transepidermal water loss.	Shin KO et al, 2020[52]
	In vivo study	It can upregulate the expression of TGF-β, bFGF, VEGF, and IL-10, while downregulating the pro-inflammatory cytokine IL-6. By activating the TGF-β/Smad2/3 signaling pathway, it can promote the repair and regeneration of the skin barrier and enhance the expression of hyaluronan synthase 1.	Li M et al, 2025[53]
	A retrospective clinical evaluation trial	A total of 72 female patients were enrolled in the study, with results showing significant reduction in skin wrinkles, along with improvements in both skin elasticity and hydration status.	Svolacchia F et al, 2024[54]
Amelioration of pigmentation	A prospective, split-face, randomized placebo-controlled trial	Twenty-one volunteers participated in this study. The results showed that AMSCs-Exos could significantly reduce melanin content; however, their activity in inhibiting melanin production has certain limitations and gradually weakens over time. Further improving the transdermal delivery efficiency of AMSCs-Exos will help enhance their overall efficacy.	Cho BS et al, 2020[32]

(*Continued*)

Table 1 (Continued).

Categories of Anti-Aging Effects	Study Type	Findings	Ref.
	In vivo study;[55] In vitro study[56–59]	AMSCs-Exos contain miR-137, miR-145, and miR-330-5p.[32] miR-137 regulates melanocyte function by targeting MITF, inhibits tyrosinase activity, and thereby reduces melanin synthesis. miR-145 can not only inhibit melanin production by targeting MITF and TYR, but also suppress melanosome transport by directly targeting Myo5a, thus alleviating pigmentation. miR-330-5p inhibits melanin synthesis in melanoma cells by targeting tyrosinase.	Dong C et al, 2012;[55] Bemis LT et al, 2008;[56] Rambow F et al, 2014;[57] Dynoodt P et al, 2013;[58] Liu Y et al, 2019[59]
Scar restoration	In vitro study and In vivo study	During the wound healing process in mice, it exerts a stage-specific regulatory effect on collagen synthesis: it can significantly promote collagen production in the early stage of healing, while effectively inhibiting the excessive synthesis of collagen in the late stage of healing, thereby significantly reducing scar formation; furthermore, its promoting effect on wound healing is mainly mediated by activating the PI3K/Akt signaling pathway.	Hu L et al, 2016;[60] Zhang W et al, 2018[51]
	In vivo study	It can regulate the ratio of TGF-β3 to TGF-β1, maintain and enhance the dynamic balance between type III collagen and type I collagen; meanwhile, it can also regulate the ratio of MMP3 to TIMP1, achieve effective remodeling of ECM, and ultimately promote the formation of scar-free ECM.	Wang L et al, 2017[61]
	In vitro study and In vivo study	miR-192-5p can inhibit the differentiation of fibroblasts into myofibroblasts, reduce collagen synthesis, and thereby effectively alleviate the formation of hypertrophic scars by targeting IL-17RA and regulating the Smad signaling pathway.	Li Y et al, 2021[62]
	In vivo study	miR-29a can reduce collagen deposition, inhibit the abnormal activation of fibroblasts, and thereby alleviate the formation of pathological scars by suppressing TGF-β2/Smad3 signaling pathway.	Yuan R et al, 2021[63]
	In vitro study;[64] Ex vivo study[65]	Inhibition of TGF-β1/Smad signaling pathway can promote the apoptosis of keloid fibroblasts; meanwhile, inhibition of TGF-β2/Smad3 and Notch-1 signaling pathways can effectively reduce the formation of keloids.	Wu ZY et al, 2021;[64] Li J et al, 2022[65]
	A prospective, double-blind, randomized, split-face trial	A total of 25 volunteers with atrophic acne scars were included in this study. The results showed that AMSCs-Exos could significantly improve the effectiveness of atrophic acne scar treatment and ensure treatment safety, providing a reliable basis for the clinical intervention of this condition.	Kwon HH et al, 2020[33]

(*Continued*)

Table 1 (Continued).

Categories of Anti-Aging Effects	Study Type	Findings	Ref.
Hair regeneration	In vivo study	It can promote hair follicle regeneration by upregulating the expression levels of PDGF and VEGF in skin tissue, while downregulating the expression level of TGF-β1, thereby creating a favorable microenvironment for hair follicle regeneration.	Wu J et al, 2021[66]
	In vitro study and In vivo study	miR-122-5p can improve the inhibitory effect of DHT on hair follicles by activating the Wnt/β-catenin signaling pathway and inhibiting TGF-β/SMAD3 signaling pathway, thereby promoting the normal growth of hair follicles.	Liang Y et al, 2023[67]
	In vitro study and In vivo study	It can improve the inhibitory microenvironment of hair follicles in immune-mediated alopecia by downregulating the expression levels of miR-22 and the inflammatory cytokine TNF-α, while activating the Wnt/β-catenin signaling pathway, thereby promoting hair follicle regeneration.	Li Y et al, 2022[68]
	An uncontrolled retrospective clinical trial	A total of 39 patients were recruited to participate in this study. The results showed that AMSCs-Exos could significantly increase hair density and hair shaft thickness; furthermore, no obvious adverse reactions were observed throughout the entire treatment cycle, suggesting that AMSCs-Exos have good safety.	Park BS et al, 2022[69]

AMSCs-Exos promote the synthesis of ceramides, reduce the levels of pro-inflammatory cytokines, and significantly decrease transepidermal water loss.[52] Hyaluronic acid, a glycosaminoglycan with strong water-retaining capacity, plays a critical role in maintaining tissue hydration, including that of the skin.[74] In a photoaged rat model, Li et al further demonstrated that AMSCs-Exos upregulate the expression of TGF-β, bFGF, VEGF, and interleukin-10 (IL-10), while downregulating the pro-inflammatory cytokine IL-6. Through activation of the TGF-β/Smad2/3 signaling pathway, they promote skin barrier repair and regeneration. Notably, AMSCs-Exos also enhance the expression of hyaluronic acid (HA) synthase 1, suggesting a potential role in improving skin hydration.[53] Additionally, Svolacchia et al conducted a photodamage treatment study using autologous AMSCs-Exos delivered through mesotherapy in 72 female participants aged 34 to 68. The treatment resulted in significant reductions in skin wrinkles and improvements in skin elasticity and hydration, with no notable adverse effects observed.[54]

Anti-Pigmentation

Hyperpigmentation is caused by the excessive synthesis of melanin by melanocytes and its uneven distribution within epidermal cells, which may lead to the appearance of sunspots, freckles, age spots, or melisma.[75,76] The production of melanin involves a series of enzymatic reactions, in which tyrosinase (TYR), TYR-related protein 1, and TYR-related protein 2 play essential roles. Among them, TYR functions as the rate-limiting enzyme in melanogenesis, while the microphthalmia-associated transcription factor (MITF) regulates the expression of these proteins.[77] The development of hyperpigmentation is typically associated with dysregulation at one or more steps of the melanin synthesis process.[78] Such skin conditions not only affect physi-cal appearance but may also have a negative impact on patients' psychological well-being and social interactions, ultimately reducing their overall quality of life. Although various skin-whitening products are available on the market, their efficacy is often limited and may be accompanied by adverse side effects to

varying degrees.[79] Therefore, identifying safe and effective approaches to alleviate or improve hyperpigmentation remains a pressing challenge.

Cho et al conducted in vitro experiments using B16F10 melanoma cells and found that AMSCs-Exos significantly reduced intracellular melanin levels, irrespective of the presence of α-melanocyte-stimulating hormone. Furthermore, a prospective, split-face, double-blind, randomized, placebo-controlled clinical trial involving 21 volunteers with hyperpigmentation demonstrated a noticeable decline in melanin levels in the treatment group beginning at week 2. By week 4, the difference between the treatment and placebo groups reached statistical significance, and by week 8, the difference became highly significant. Interestingly, the reduction in melanin was more pronounced in participants under the age of 50. Throughout the study and after its completion, no adverse reactions were reported, suggesting that the exosome-based formulation is both well tolerated and safe for cosmetic use.[32] In addition, Cho et al identified the presence of miR-137, miR-145, and miR-330-5p in AMSCs-Exos through small RNA sequencing in their preliminary study.[32] In melanoma cells, miR-137 regulates melanocyte function by targeting MITF, inhibits the activity of TYR, and thereby reduces melanin synthesis.[55–57] Moreover, miR-145 not only suppresses melanin production by targeting MITF and TYR, but also alleviates pigmentation by inhibiting melanosome transport through direct targeting of Myo5a.[58] Similarly, miR-330-5p targets TYR to inhibit melanin synthesis in melanoma cells.[57,59]

Anti-Scarring

The wound healing process of the skin consists of three distinct yet overlapping phases: the inflammatory phase, the proliferative phase, and the remodeling phase. Scar formation is a common outcome of wound healing, and collagen synthesis and degradation play critical roles in this process. In the early proliferative phase, fibroblasts are responsible for the synthesis and secretion of collagen. In the later proliferative stage, fibroblasts differentiate into myofibroblasts, which produce large amounts of collagen, leading to ECM accumulation and promoting wound contraction. During the remodeling phase, MMPs secreted by fibroblasts remodel the scar tissue, while both fibroblasts and myofibroblasts undergo apoptosis, resulting in reduced ECM synthesis.[80] The extent of scar formation is influenced by the intensity and duration of the inflam-matory response, as well as the balance between collagen synthesis and degradation. The development of hypertrophic scars and keloids is primarily due to dysregulation of fibroblast and myofibroblast proliferation and apoptosis, leading to excessive collagen deposition and impaired degradation, ultimately resulting in ECM overaccumulation.[81] In contrast, atrophic scars, often seen after acne infection, are primarily caused by local collagen fiber loss or contraction, and are characterized by depressions in the skin surface.[82]

In studies investigating anti-scar therapies using AMSCs-Exos, Hu et al found that AMSCs-Exos exert a stage-specific regulatory effect on collagen synthesis during wound healing in mice: they significantly promote collagen production in the early healing phase, while effectively inhibiting excessive collagen generation in later stages, thereby markedly reducing scar formation.[60] This acceleration of wound healing is primarily mediated through activation of the PI3K/Akt signaling pathway.[51] Further elucidating the scar-reducing mechanisms, Wang et al demonstrated that AMSCs-Exos can regulate the ratio of TGF-β3 to TGF-β1, maintaining and enhancing the dynamic balance between type III and type I collagen. Additionally, they modulate the ratio of MMP3 to tissue inhibitor of metalloproteinase 1 (TIMP1), enabling effective ECM remodeling and ultimately promoting the formation of scar-free ECM.[61] miRNAs, as key components of exosomes, play a critical role in intercellular communication. Li et al demonstrated in a murine hypertrophic scar model that miR-192-5p derived from AMSCs-Exos targets IL-17RA and modulates the Smad signaling pathway, thereby inhibiting the differentiation of fibroblasts into myofibroblasts, reducing collagen synthesis, and effectively alleviating hypertrophic scar formation.[62] Yuan et al found that in both in vitro and animal models of hypertrophic scars, miR-29a in AMSCs-Exos attenuates scar formation by suppressing the TGF-β2/Smad3 signaling pathway.[63] Currently, effective treatments for keloids remain limited. Wu et al reported in an in vitro model that inhibition of the TGF-β1/Smad signaling pathway promotes apoptosis of keloid fibroblasts and thus suppresses keloid formation.[64] Furthermore, Li et al confirmed in both in vitro and ex vivo keloid models that AMSCs-Exos can effectively reduce keloid formation by inhibiting both the TGF-β2/Smad3 and Notch-1 signaling pathways.[65] Additionally, Kwon et al conducted a 12-week prospective, double-blind, randomized, split-face clinical study involving 25 volunteers with

atrophic acne scars. The study evaluated the therapeutic efficacy of AMSCs-Exos combined with fractional CO_2 laser therapy. The results showed that AMSCs-Exos significantly enhanced both the effectiveness and safety of treatment for atrophic scars.[33] Given the current scarcity of clinical evidence regarding the treatment of atrophic scars, this study provides valuable experimental and clinical support for optimizing therapeutic strategies.

Anti-Hair Loss

The normal hair growth cycle consists of three phases: anagen (growth phase), catagen (regression phase), and telogen (resting phase). Approximately 80–85% of hair follicles are in the anagen phase, around 2% in the catagen phase, and about 10–15% in the telogen phase.[83] During the anagen phase, platelet-derived growth factor (PDGF) and VEGF are involved in the regulation of hair follicle growth, whereas TGF-β1 pro-motes the entry of hair follicles into the catagen phase by inducing apoptosis-related factors.[84–86] The Wnt/β-catenin signaling pathway also plays a pivotal role in the regulation of the hair growth cycle.[87] Hair loss is the result of a complex interplay of multiple factors, including genetic predisposition, hormonal imbalances, immune dysfunction, psychological stress, and aging. These factors may disrupt the normal ratio between anagen and telogen phases, leading to a premature transition of hair follicles into the resting phase and, ultimately, hair shedding.[88] Therefore, a key therapeutic strategy for hair regeneration is to effectively induce hair follicles in the catagen and telogen phases to reenter the anagen phase.

Wu et al demonstrated that AMSCs-Exos promoted hair follicle regeneration in a mouse model of alopecia by upregulating PDGF and VEGF expression levels in skin tissue while downregulating TGF-β1 levels.[66] The primary mechanism of androgenetic alopecia involves elevated local levels of dihydrotestosterone (DHT) in the scalp, leading to progressive miniaturization of hair follicles.[89] Liang et al applied AMSCs-Exos to both in vitro and in vivo models of androgenetic alopecia, and found that the miR-122-5p contained in these exosomes could activate the Wnt/β-catenin signal-ing pathway and inhibit the TGF-β/SMAD3 pathway, thereby promoting normal hair follicle growth.[67] Moreover, immune dysfunction is also recognized as an important pathogenic factor in hair loss. miR-22 has been identified as a key regulator of the transition from the anagen to the catagen phase. In a mouse model of alopecia, Li et al confirmed that AMSCs-Exos could promote hair follicle regeneration by downregulating the expression of miR-22 and the inflammatory cytokine TNF-α, while simultaneously activating the Wnt/β-catenin pathway, offering new insights into the treatment of immune-mediated alopecia.[68] Notably, Park et al conducted a 12-week uncontrolled retrospective study to evaluate the therapeutic effects of AMSCs-Exos in 39 patients with alopecia (including 27 men and 12 women, aged 20 to 66 years). The results showed that AMSCs-Exos significantly increased hair density and shaft thickness, with no notable adverse effects observed throughout the treatment period.[69]

Current Application Status of Commercial Exosome Products

Currently, no exosome-related products have received formal approval from the US FDA or the European Medicines Agency (EMA). The main reasons include the lack of standardized manufacturing processes, insufficient research on their mechanisms of action, immature regulatory frameworks, and numerous technical challenges in large-scale production.[90] It is noteworthy that the FDA currently classifies exosomes as biological products and prohibits their use for systemic therapy; however, in certain cases, if used only on the superficial skin layer locally, they may be regulated as cosmetic ingredients.[91]

According to a 2023 review by Asadpour et al, approximately 114 companies and clinics worldwide are engaged in the production of stem cell-derived exosomes, with the vast majority located in the United States. By source classification, about 60 companies focus on allogeneic exosomes, over 30 produce autologous exosomes, and more than 20 have unclear exosome origins. Regarding tissue sources, 38% of products did not disclose specific origins; among those disclosed, blood-derived exosomes account for 24%, amniotic fluid-derived for 10%, adipose tissue and bone marrow each account for 9%, and umbilical cord-derived account for 7%. In terms of therapeutic indications, 48 institutions provide skincare-related services, 42 focus on anti-aging treatments, 36 on hair loss treatments, and some products are also applied for chronic and neurological disease interventions. This indicates that skincare, anti-aging, and hair loss treatments are currently the most common fields for exosome applications.[90] Specifically, BENEV Inc. and ExoCoBio Inc. have jointly developed a product based on AMSCs-Exos. This product enhances skin barrier function and improves

skin hydration by inhibiting the expression of inflammatory cytokines and promoting ceramide synthesis, thereby achieving significant moisturizing effects.[92] Additionally, the company developed another AMSCs-Exos product inspired by research findings showing that AMSCs-Exos derived from young mice could alleviate oxidative stress and improve or reverse aging in old mice. This product is primarily used for intervening in skin aging, hair loss, and pigmentation related to aging.[90,93] Notably, the AMSCs-Exos product developed by ExoCoBio Inc. was also involved in a clinical study with 25 patients suffering from atrophic acne scars. The results demonstrated that AMSCs-Exos combined with fractional CO_2 laser treatment significantly enhanced the therapeutic effect on acne scars.[33]

Given the current lack of definitive data on the safety and efficacy of exosomes, to protect consumer health and reduce economic risks, exosome-based interventions in the skincare field should be conducted under strict supervision by regulatory authorities.

Challenges and Limitations

Despite the significant potential of AMSCs-Exos in the field of anti-skin aging, their research and application still face multiple challenges, and a rational perspective is needed to examine their current state of development.

At the level of technical bottlenecks and standardization, exosome isolation currently relies on techniques such as ultracentrifugation, ultrafiltration, and immunocapture. However, these methods vary significantly in terms of purity, yield, and bioactivity, For example, ultracentrifugation is prone to contamination with protein aggregates, while ultrafiltration may cause structural damage to exosomes.[28] Meanwhile, there is a lack of unified identification standards in the field; existing techniques such as TEM, NTA, and Western blot can only partially characterize the physical and chemical properties of exosomes, and fail to quantify their functional activity (eg, the load of specific microRNAs (miRNAs) or growth factors), directly reducing the comparability of results across different studies.[28] Additionally, in the entire process from adipose tissue acquisition and AMSC culture to exosome extraction, key steps such as enzymatic digestion time, culture conditions, and storage temperature exhibit inter-laboratory variations, leading to significant fluctuations in the composition and activity of exosomes. Taking AMSC isolation methods as an example, the miRNA expression profiles of exosomes secreted by AMSCs obtained via enzymatic digestion and mechanical methods can differ by more than 20%, seriously compromising the stability of clinical applications.[24,25,28]

In terms of clinical translation, core barriers focus on insufficient evidence-based medicine data and delayed optimization of delivery technologies. Most existing clinical studies are designed with small sample sizes ($n < 30$) and short follow-up periods (follow-up < 6 months), lacking support from large-scale ($n > 100$), long-term (> 1 year) safety and efficacy data.[32,33,46] The dose-effect relationship of exosomes remains unclear, with topical application concentrations varying by up to 10-fold across different studies, and systematic research on the "effective dose threshold" and "maximum tolerated dose" is still lacking.[32,46] Meanwhile, despite their inherent capacity for natural penetration of the skin barrier, exosomes demonstrate extremely low enrichment efficiency in the dermis; merely around 15% to 20% of them successfully reach the microenvironment surrounding fibroblasts. Existing methods to enhance delivery efficiency (eg, microneedles, ultrasonic penetration) can increase local concentrations but may raise the risk of skin irritation, and their long-term safety has not been scientifically verified.[28,46]

Safety concerns also cannot be ignored. On one hand, while autologous AMSCs-Exos exhibit low immunogenicity, long-term repeated administration may pose unforeseen risks. For instance, critical questions remain unanswered, such as whether miRNAs carried by exosomes interfere with normal cell cycle regulation (eg, by inducing abnormal proliferation) or whether their lipid components trigger local chronic inflammation.[27,32] Moreover, only a few studies have follow-up periods exceeding 6 months, and none have monitored long-term pathological changes in skin tissue.[32,46] On the other hand, contamination risks in the production process are difficult to avoid: contaminants such as mycoplasma and endotoxins may be introduced during cell culture; chemical reagents used in exosome isolation (eg, polyethylene glycol in polymer precipitation) may remain as residues and cause skin allergies; furthermore, the preparation of autologous exosomes requires individualized operations, and inadequate quality control (eg, excessive cell passage numbers) can easily lead to decreased exosome activity or abnormal function.[28]

In addition, inconsistencies in some research results within the field highlight scientific controversies. Regarding dose dependence, low-concentration AMSCs-Exos (10 μg/mL) can reduce collagen degradation by inhibiting MMPs, while

high concentrations of AMSCs-Exos (100 μg/mL) may activate the nuclear factor-κB pathway, leading to increased secretion of pro-inflammatory factors such as IL-6, thereby highlighting the complexity of dose-dependent effects.[47,53] In scar repair, AMSCs-Exos show a significant improvement effect on fresh scars (formed < 3 months), but have minimal impact on old scars (> 6 months). This is presumably related to the high degree of fibrosis in old scar tissue and reduced exosome penetration ability, and this mechanism requires further verification.[60,61]

In summary, there remains a clear gap in the translation of AMSCs-Exos from basic research to clinical application. In the future, these challenges need to be gradually addressed by establishing a full-process standardized production system, conducting large-scale long-term clinical trials, and optimizing targeted delivery technologies. At the same time, it is necessary to rationally define the current application boundaries of AMSCs-Exos and avoid overexaggerating their efficacy.

Personalized Skincare

With the advent of the Fourth Industrial Revolution, represented by AI, the beauty industry is rapidly transitioning from traditional basic cosmetics to a new era centered on personalized skincare, with customized cosmetics at its core. Currently, the global customized cosmetics market is not only primarily concentrated in North America and Europe, but also widely distributed across countries and regions in Asia and Oceania.[94] Customized cosmetics are products designed to meet the unique needs of individuals, primarily by repackaging existing formulations or mixing them with other ingredients to achieve personalized compositions. These products are characterized by their diverse types and small production batches, enabling them to respond more precisely to the increasingly diverse and personalized demands of consumers in the beau-ty sector.[94,95] A survey conducted by Kim et al involving 1,084 consumers revealed that 57.2% of respondents expressed a willingness to purchase customized cosmetics. However, a significant proportion of consumers voiced concerns regarding the microbiological safety (59.2%) and chemical safety (69.4%) of such products, indicating widespread anxiety about their safety. To advance customized cosmetics from an early trial stage to a mature market with strong brand loyalty, it is essential to ensure both product safety and efficacy.[94] Therefore, the production of customized cosmetics should be regulated under relevant cosmetic laws and strictly adhere to GMP. Only by doing so can consumers' self-efficacy be strengthened, thereby promoting the transformation of purchase intentions into actual buying behavior. AI plays a crucial role in this transformation. AI can not only perform high-precision skin condition assessments to help consumers develop scientifically personalized skincare regimens but also monitor skin changes in real-time to accurately evaluate the effects of cosmetic products. Moreover, AI can objectively analyze consumers' emotional responses to gauge product satisfaction and further predict their purchasing intentions. Considering the individual differences in fragrance preferences, AI can also assist users in precisely selecting their preferred scents from a wide range of options, significantly enhancing the personalization and user satisfaction of customized cosmetic experiences.[96]

Meanwhile, although exosomes have shown broad application potential as emerging bioactive ingredients in the field of personalized skincare, their production and application still face multiple challenges. At present, exosome technology lacks standardized manufacturing processes and comprehensive regulatory frameworks, and there are numerous technical bottlenecks in large-scale production.[90] Particularly in terms of safety and efficacy, the variability in sources, batch differences, and uncertainties in preparation and delivery processes have significantly hindered their widespread use in clinical therapy and the beauty industry.[97] In contrast, AMSCs-Exos hold potential for use in personalized skincare products due to their lack of exogenous pathogen transmission risks, absence of immune rejection, and no oncogenic concerns.[98] For example, ExoCoBio launched an exosome cream that requires mixing with exosomes prior to use. Studies have shown that the product can be stably preserved for up to 21 days at 4°C to 8°C.[99] This finding suggests that it is feasible to amplify autologous AMSCs in vitro, extract exosomes from a portion of the cells, and produce customized cosmetics for three-week use while maintaining the bioactivity and functional effects of the exosomes. The remaining cells can be cryopreserved in liquid nitrogen for fresh exosome extraction during follow-up visits every three weeks. This short-cycle follow-up production and usage mechanism not only facilitates timely feedback collection from consumers for formulation optimization and personalized adjustments, but also enables the accumulation of

valuable clinical data, thereby promoting the continued evolution of personalized skincare products toward greater precision and scientific rigor.

Conclusion

In recent years, stem cell-derived exosomes have emerged as a research focus in the cosmetics and skincare industry due to their potential in skin repair and regeneration. However, the development of this field remains constrained by several core bottlenecks. On the one hand, heterogeneity of cell sources results in significant differences in bioactive components (eg, miRNAs, proteins) among exosomes, directly leading to inconsistent anti-aging efficacy and greater uncertainty in clinical application. On the other hand, the lack of standardized production systems (eg, unified criteria for exosome isolation and purification, storage quality control, and activity detection) and technical barriers to large-scale manufacturing (eg, time-consuming ultracentrifugation, membrane fouling during ultrafiltration, and high costs) severely limit their translation into clinical and industrial practice.

Against this backdrop, research on AMSCs-Exos offers a promising direction for overcoming these challenges. Functionally, AMSCs-Exos have been demonstrated to exert multiple well-defined anti-aging effects on the skin, including scavenging ROS via activation of the Nrf2 pathway, promoting collagen synthesis through regulation of the TGF-β/Smad pathway (anti-wrinkle), repairing the skin barrier by enhancing ceramide synthesis and upregulating hyaluronan synthase (anti-dryness), inhibiting tyrosinase via miR-137/330-5p targeting (anti-pigmentation), maintaining collagen homeostasis and inhibiting myofibroblast differentiation (anti-scarring), and promoting hair follicle regeneration through activation of the Wnt/β-catenin pathway (anti-hair loss). In terms of safety and applicability, autologous AMSCs-Exos provide distinct advantages, including low immunogenicity (no MHC class II expression), no risk of exogenous pathogen transmission, and no tumorigenicity. Moreover, they are compatible with a small-scale preparation for short-term use model (eg, following in vitro expansion of autologous AMSCs, exosomes can be extracted to generate customized products stable for 21 days, while surplus cells are cryopreserved in liquid nitrogen for future use). This strategy not only mitigates the safety risks of allogeneic exosomes but also circumvents the technical challenges of large-scale production, positioning AMSCs-Exos as an ideal bioactive ingredient for personalized skincare applications.

Meanwhile, technological innovations driven by AI are accelerating the transition of the cosmetics industry from "traditional basic skincare" to "precision personalized skincare." AI can provide robust data support for the development of customized regimens through high-resolution skin monitoring (eg, real-time assessment of stratum corneum hydration, collagen density, and pigment distribution), dynamic efficacy tracking, and emotional preference analysis. Notably, the "small-scale customized production characteristics" of AMSCs-Exos are highly aligned with this trend: the integration of AI and AMSCs-Exos enables a closed loop from "AI-based demand assessment to precise AMSCs-Exos adaptation" (eg, tailoring formulations enriched in miR-1246 for individuals with photoaging), while also allowing the accumulation of clinical data through short-term follow-ups (eg, improvement in skin elasticity, reduction in melanin levels, and incidence of adverse reactions). This model not only further validates product efficacy but also introduces a new paradigm of personalized skincare that integrates bioactive ingredients with intelligent assessment.

Nevertheless, several practical issues must be addressed before broader implementation. Consumers remain concerned about the microbial and chemical safety of customized cosmetics (eg, collagenase residues in exosome preparations, degradation of bioactive components during storage), and AMSCs-Exos-based products have yet to receive formal approval from regulatory authorities (eg, FDA, EMA). To this end, future work should prioritize three areas: first, establishing a comprehensive standardized system for AMSCs-Exos, including harmonized protocols for adipose tissue collection (eg, standardized liposuction/biopsy procedures), exosome isolation (eg, promotion of tangential flow filtration), activity assays (eg, defined miRNA/protein thresholds), and storage protocols (eg, −80 °C storage with trehalose as a cryoprotectant) to address current regulatory and technical gaps. Second, incorporating customized AMSCs-Exos products into the cosmetic regulatory framework, ensuring strict compliance with GMP standards, and addressing safety concerns through third-party quality control to build consumer trust. Third, conducting large-scale, long-term clinical trials (eg, combining AMSCs-Exos with fractional CO2 laser therapy for atrophic acne scars, or autologous exosome intervention for androgenetic alopecia) to generate high-quality evidence and clarify essential clinical parameters such as

effective dose thresholds, target populations (eg, improved response in patients with hyperpigmentation under 50 years old), and optimal combination regimens.

In conclusion, with their well-defined anti-aging functions, excellent safety profile, and compatibility with customization, AMSCs-Exos have become a pivotal bridge connecting basic research on skin anti-aging with the clinical translation of personalized skincare. Looking ahead, the integration of standardized system development, AI-driven technological synergy, and evidence-based clinical validation will not only accelerate the clinical application of AMSCs-Exos in treating conditions such as photoaging, scarring, and hair loss, but also provide the cosmetics industry with a new direction characterized by being science-driven, safe and controllable, and precisely tailored—ultimately ushering in a new era of precision anti-aging in dermatology and skincare.

Funding

This work was supported by the National Research Foundation of Korea (grant numbers RS-2023-00220408).

Disclosure

The authors have no financial conflicts of interest in this work.

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