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MINI REVIEW

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The microbiome and skin health: Emerging roles in dermatological therapy

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ABSTRACT

The human skin hosts a diverse array of microorganisms, collectively referred to as the skin microbiome. This complex ecosystem, composed primarily of bacteria, fungi, and viruses, plays a crucial role in maintaining skin health by modulating immune responses, protecting against pathogenic invasion, and contributing to the integrity of the skin barrier. Recent advancements in metagenomic sequencing and microbial profiling have shed light on the dynamic interactions between host skin and its resident microbiota, revealing significant implications for both health and disease.

Alterations in the composition or function of the skin microbiome, referred to as dysbiosis, have been increasingly associated with various dermatological conditions, including acne vulgaris, atopic dermatitis, psoriasis, and rosacea. These findings suggest that microbial imbalance may not only reflect but also actively drive inflammatory and immune-mediated skin disorders. Gaining insight into these interactions presents promising opportunities for developing new therapeutic approaches.

New therapeutic strategies focused on restoring microbial balance involve the application of topical probiotics, prebiotics, postbiotics, and microbiome transplantation. Such approaches are designed to enhance beneficial microbial populations, suppress pathogenic strains, and support skin homeostasis with minimal side effects compared to conventional therapies. Furthermore, personalized dermatological treatments based on individual microbiome profiles represent a promising avenue for future clinical practice.

Despite growing enthusiasm, significant challenges remain, including the standardization of sampling techniques, interpretation of metagenomic data, and regulatory frameworks governing live microbial products. Nonetheless, the integration of microbiome science into dermatology holds great potential to revolutionize the management of chronic skin diseases.

KEYWORDS

Skin microbiome; Dysbiosis; Dermatological disorders; Probiotics; Cutibacterium acnes; Atopic dermatitis

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Introduction

The human skin serves not only as a physical barrier but also as a complex ecosystem that supports a diverse population of microorganisms, collectively known as the skin microbiome. This community of microorganisms, comprising bacteria, fungi, viruses, and mites, largely exists in a symbiotic relationship with the human host [1]. Far from being passive residents, these microbes actively contribute to skin physiology by enhancing immune responses, defending against pathogenic invasion, and supporting the maintenance of skin barrier integrity.

Advancements in high-throughput sequencing and metagenomic technologies have revolutionized our understanding of the skin microbiome. These tools have enabled scientists to identify previously undetectable microbial species and explore their functional roles in maintaining skin health. Research now highlights the dynamic nature of this ecosystem, showing how factors like age, environment, hygiene practices, antibiotic use, and underlying health conditions can influence microbial composition and function [2, 3].

Disruptions in the balance of the skin microbiome, often termed dysbiosis, are increasingly recognized as contributing factors in a variety of dermatological diseases. Conditions such as acne vulgaris, atopic dermatitis, psoriasis, and rosacea have been linked to specific microbial shifts or overgrowths, suggesting that an imbalanced microbiome may not only reflect but also exacerbate inflammatory skin responses [4].

As a result, there is growing interest in targeting the microbiome as a novel approach to dermatological treatment. Unlike conventional therapies that aim to suppress symptoms or eliminate pathogens, microbiome-based strategies seek to restore microbial equilibrium [5]. These may include the use of topical probiotics, prebiotics, postbiotics, and even microbiome transplantation to rebalance the microbial environment and promote skin health.

This mini-review aims to provide an overview of the role of the skin microbiome in both health and disease, examine emerging therapeutic strategies that focus on microbial modulation, and discuss the current challenges and future directions of microbiome-centred dermatology. With advancing knowledge, the skin microbiome is emerging as a key foundation for personalized and precision-based dermatological treatments [6].

The Skin Microbiome in Health

Composition of the healthy skin microbiome

The healthy skin microbiome is a complex and diverse

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ecosystem composed of bacteria, fungi, viruses, and microscopic arthropods such as mites. Among these, bacteria are the most extensively studied and make up the majority of the microbial population. The dominant bacterial genera include Staphylococcus (e.g., Staphylococcus epidermidis), Cutibacterium (formerly Propionibacterium, e.g., Cutibacterium acnes), and Corynebacterium. These microbes colonize the skin in patterns influenced by anatomical location, moisture levels, pH, temperature, and sebum content [7, 8]. For instance, Cutibacterium acnes thrives in oily areas such as the face and back, while Staphylococcus epidermidis is more abundant in moist areas like the armpits and groin.

Fungal species, particularly from the genus Malassezia, are commonly found on sebaceous skin and contribute to lipid metabolism. Viruses, including bacteriophages, are also part of the skin microbiome, although their roles are less well understood. Mites such as Demodex reside in hair follicles and sebaceous glands and are considered part of the normal flora [9].

This balanced microbial community plays a vital role in skin immunity, barrier integrity, and overall dermatological health, adapting constantly to environmental and host-related factors.

Protective functions against pathogens

The skin microbiome serves a crucial protective function by preventing the colonization of harmful pathogens on the host's skin. Commensal microbes such as Staphylococcus epidermidis, Cutibacterium acnes, and Corynebacterium species form a protective barrier by occupying ecological niches on the skin and competing with pathogens for nutrients and attachment sites. These beneficial microbes also produce antimicrobial peptides (AMPs), organic acids, and bacteriocins that inhibit the growth of invading organisms [10, 11]. For instance, S. epidermidis secretes specific molecules that suppress the proliferation of Staphylococcus aureus, a major contributor to skin infections and inflammation.

In addition to biochemical defenses, the skin microbiota contributes to maintaining an acidic pH, which further limits pathogen survival. This microbial shield not only reduces the likelihood of infections but also supports immune tolerance by interacting with host immune cells. Collectively, these protective functions help preserve skin health and reinforce its role as a frontline immune barrier [12].

Immune modulation and tolerance

The skin microbiome plays a key role in shaping and regulating the immune system. Commensal microbes interact with skin immune cells, such as keratinocytes and Langerhans cells, through molecular signals that help distinguish between harmless and harmful organisms. These interactions promote immune tolerance toward beneficial microbes while maintaining vigilance against pathogens. For example, Staphylococcus epidermidis can stimulate the production of antimicrobial peptides without triggering inflammation, supporting immune balance. Additionally, microbial metabolites influence cytokine production and help modulate inflammatory responses [13, 14]. This fine-tuned communication between microbes and the immune system is essential for preventing chronic inflammation, allergic reactions, and autoimmune skin conditions. Overall, the microbiome helps maintain a stable, responsive, and tolerant immune environment on the skin.

Maintenance of skin barrier integrity

The skin microbiome is essential for maintaining the integrity and functionality of the skin barrier. Commensal microbes contribute to barrier integrity by producing beneficial metabolites such as short-chain fatty acids, ceramides, and antimicrobial peptides. These substances help maintain the skin's acidic pH, which is essential for inhibiting pathogen growth and preserving lipid organization [15]. Microbial activity also enhances the production of tight junction proteins and promotes keratinocyte differentiation, both of which strengthen the skin's physical barrier.

Furthermore, a balanced microbiome supports moisture retention and prevents trans-epidermal water loss, helping to keep the skin hydrated and resilient against environmental stressors. Disruption of the microbial balance can weaken the barrier, making the skin more susceptible to infections, inflammation, and irritants [16]. Thus, maintaining a healthy microbiome is integral to upholding the skin's protective, structural, and immunological functions.

Factors influencing microbiome stability

The stability of the skin microbiome is influenced by a variety of intrinsic and extrinsic factors that can alter its composition and function. Intrinsic factors include age, genetics, hormonal changes, and individual immune responses. For instance, newborns have a different microbial profile compared to adults, and hormonal fluctuations during puberty or menopause can shift microbial populations [17].

Extrinsic factors such as climate, hygiene habits, skincare products, antibiotic use, and environmental exposures also play a significant role. Frequent washing, the use of harsh soaps or antiseptics, and excessive application of cosmetic products can disrupt the microbial balance, leading to a reduction in beneficial microbes and an increase in opportunistic pathogens [18]. Seasonal changes and geographical location further influence skin microbial diversity through variations in humidity, temperature, and UV exposure.

Despite these influences, the skin microbiome demonstrates a remarkable ability to recover and maintain homeostasis in healthy individuals. Understanding these factors is essential for designing targeted interventions to support or restore microbiome balance in dermatological care.

Dysbiosis and Dermatological Disorders

Maintaining a balanced skin microbiome is crucial for preserving overall dermatological health. When this balance is disrupted, a condition known as dysbiosis can contribute to the onset or worsening of various skin disorders. Rewrite the below sentence.

One of the most studied examples is atopic dermatitis (AD), where dysbiosis is characterized by a significant increase in Staphylococcus aureus colonization and a concurrent decrease in beneficial Staphylococcus epidermidis. S. aureus exacerbates inflammation and disrupts the skin barrier, intensifying the symptoms of AD [19]. Treatments aimed at

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restoring microbial balance, such as emollients or topical probiotics, have shown promise in alleviating symptoms.

In acne vulgaris, an overabundance of Cutibacterium acnes strains with pro-inflammatory properties contributes to pore blockage and inflammation. While C. acnes is a normal part of healthy skin, dysbiosis involving specific pathogenic strains, along with host factors like sebum production and hormonal influence, triggers acne lesions.

Psoriasis is another condition associated with microbial imbalance. Although the exact microbial triggers are not fully understood, shifts in bacterial and fungal populations, especially an increase in Malassezia species, have been linked to immune dysregulation and keratinocyte hyperproliferation [20]. These changes may amplify inflammatory pathways already active in genetically predisposed individuals.

In rosacea, studies suggest an increased presence of Demodex mites and associated bacteria, such as Bacillus oleronius, which may provoke immune responses and vascular inflammation. The altered microbiome likely interacts with the innate immune system, contributing to the chronic erythema and papules characteristic of the disease.

Additionally, wound healing can be delayed by dysbiosis. Pathogenic colonization of wounds often interferes with healing processes, whereas a balanced microbiome may support tissue regeneration through anti-inflammatory and antimicrobial mechanisms.

Understanding the role of dysbiosis in skin diseases highlights the importance of maintaining microbial homeostasis. This growing knowledge base provides a foundation for microbiome-targeted therapies, shifting the focus from simply eliminating pathogens to restoring ecological balance for long-term skin health.

Emerging Therapeutic Approaches

With growing insights into the skin microbiome, researchers are developing innovative treatments that focus on restoring and preserving its natural balance. These new therapies go beyond just addressing symptoms of skin diseases they aim to correct the underlying microbial imbalances, known as dysbiosis, which often contribute to skin disorders. By targeting the root causes, such approaches support both immediate relief and long-term skin health. This shift in strategy represents a more holistic and sustainable path in dermatological care, emphasizing the importance of maintaining a healthy microbial environment to prevent and manage various skin conditions effectively (Figure 1).

Topical probiotics

Topical probiotics refer to the application of live, beneficial microorganisms directly onto the skin surface. These formulations are designed to enhance the population of commensal bacteria, outcompete pathogenic organisms, and modulate immune responses. For example, Staphylococcus hominis strains have been shown to inhibit Staphylococcus aureus and reduce inflammation in atopic dermatitis [21]. Probiotics may also help strengthen the skin barrier and improve moisture retention.

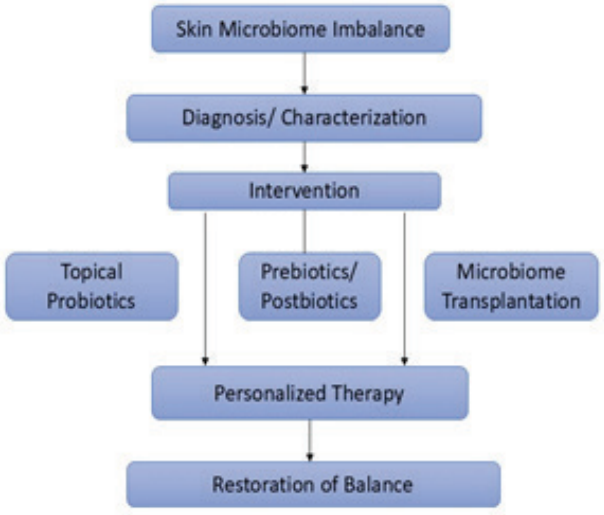

Figure 1. Therapeutic strategies targeting the skin microbiome.

Prebiotics and postbiotics

Prebiotics are non-living compounds, such as plant-derived fibers or sugars, which selectively nourish beneficial skin microbes. They create an environment that supports the growth of commensals while suppressing harmful species. Postbiotics, on the other hand, are metabolic byproducts produced by probiotics such as lactic acid, short-chain fatty acids, and antimicrobial peptides that exert therapeutic effects without the need for live organisms. Both prebiotics and postbiotics can help restore skin homeostasis and improve barrier function.

Microbiome transplantation

Inspired by the success of fecal microbiota transplantation in gut health, skin microbiome transplantation involves applying healthy microbial communities to dysbiotic skin. This technique is still in early research stages but has shown promise in small trials for conditions like eczema and chronic wounds. Reintroducing balanced microbial communities can potentially reset the skin's microbiome, offering longer-lasting results compared to conventional treatments [22].

Personalized microbiome therapy

Advancements in microbiome sequencing and bioinformatics are paving the way for personalized skin microbiome treatments. These involve profiling an individual's skin microbiota to design targeted therapies based on their unique microbial composition. Such precision medicine approaches may help optimize treatment outcomes, reduce side effects, and enhance long-term efficacy in managing chronic skin conditions.

Limitations and prospects

While these microbiome-based therapies hold great promise, challenges remain. Standardization, regulatory approval, and long-term safety need further investigation. However, ongoing clinical trials and innovations continue to support the potential of microbiome-targeted interventions as the future of dermatological care.

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Challenges and Future Directions

While microbiome-based therapies hold significant promise for advancing dermatological care, several challenges must be addressed. One major limitation is the lack of standardization in probiotic, prebiotic, and microbiome transplant formulations, which complicates reproducibility and regulatory approval. Individual variability in skin microbiota, influenced by genetics, environment, and lifestyle, further complicates the development of universal treatments [23]. Additionally, the long-term safety and efficacy of these interventions remain under-explored, requiring large-scale clinical trials and longitudinal studies.

Another challenge is our incomplete understanding of the skin microbiome's less dominant microbial members, their functions, and their interactions with host immunity. Current research has focused mainly on bacteria, while fungi, viruses, and mites remain understudied.

Future directions should emphasize personalized therapies guided by microbiome profiling and supported by bioinformatics and artificial intelligence. With continued research and technological advancements, microbiome-targeted treatments may become reliable, safe, and integral components of precision dermatology.

Conclusions

The skin microbiome is essential for supporting skin health by regulating immune responses, preserving barrier integrity, and maintaining overall cutaneous balance. Disruptions to this microbial ecosystem, known as dysbiosis, have been linked to a range of dermatological disorders, including atopic dermatitis, acne, psoriasis, and rosacea. As scientific understanding of skin-microbe interactions deepens, there is growing potential for microbiome-based therapies to transform dermatological care. Emerging strategies such as topical probiotics, prebiotics, postbiotics, and microbiome transplants aim to restore microbial balance and offer targeted, long-term solutions. Though challenges remain in standardization and clinical validation, these approaches highlight a paradigm shift toward personalized and preventive skin treatments. Continued research and innovation will be essential to unlocking the full therapeutic potential of the skin microbiome, paving the way for more effective and sustainable dermatological interventions.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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