



Original Research Paper

SCALP MICROBIOME AND HAIR FOLLICLE HEALTH: MICROBIAL INTERACTION ENZYMATIC ACTIVITY AND THERAPEUTIC PERSPECTIVES

Dr. Shekhar V. Kokate¹, Ms. Ashwini S. Wagcharue², Dr. Kundan J. Tiwari³ and Dr. Yogesh V. Ushir⁴

¹Associate Professor, SMBT College of B. pharmacy, Nashik, Maharashtra-422403 India

²B-Pharmacy Student, SMBT College of B. pharmacy, Nashik, Maharashtra-422403 India

³HOD, SMBT Institute of Diploma Pharmacy, Nashik, Maharashtra-422403 India

⁴Principal, SMBT College of pharmacy, Nashik, Maharashtra-422403 India

ABSTRACT

Diverse bacterial populations that live in different anatomical locations and actively support host homeostasis through interactions with epithelial tissues, immunological pathways, metabolic processes, and barrier functions make up the human microbiome. According to this theory, the skin microbiome is essential for preserving the epithelial barrier, stopping pathogen colonization, and regulating host immune responses. As a result, changes in the functional ability or composition of microorganisms can seriously impair local tissue homeostasis and initiate inflammatory pathways. The present understanding of host-microbe interactions at the epithelial boundary is summarized in this work, which emphasizes how dysbiosis affects the functions of the cutaneous and mucosal barriers. We highlight the primary processes by which changes in microbial communities cause inflammatory diseases by clarifying these immunological and metabolic dynamics. Comprehending these host-microbial interactions reveals possible targets for therapeutic intervention and offers crucial insight into the genesis of inflammatory diseases mediated by the microbiome.

Keywords: Human microbiome, Hair follicle cycle, Microbial dysbiosis, Androgenetic Alopecia, Probiotics and prebiotics, Regenerative trichology.

Abbreviation:

Abbreviations	Full forms
AA	Alopecia Areata
AGA	Androgenetic Alopecia
AMPs	Antimicrobial Peptides
AR	Androgen Receptor
BMPs	Bone Morphogenetic Proteins
CCL20	C-C Motif Chemokine Ligand 20
DHT	Dihydrotestosterone
DP	Dermal Papilla
FGF	Fibroblast Growth Factor
FGF9	Fibroblast Growth Factor 9
FFAs	Free Fatty Acids
FPHL	Female Pattern Hair Loss
GI	Gastrointestinal
HF	Hair Follicle
HFSCs	Hair Follicle Stem Cells
HF-MSCs	Hair Follicle-derived Mesenchymal Stem Cells
HPA Axis	Hypothalamic–Pituitary–Adrenal Axis
IBD	Inflammatory Bowel Disease
IGF-1	Insulin-like Growth Factor 1
IL-1 β	Interleukin-1 Beta

*Corresponding Author:

Received: 25th May, 2026; Revised: 6th July, 2026; Accepted: 28th July, 2026; Available Online: 29th August, 2026

(DOI): 10.70102/AEJ.2026.18.2.30

LGR5	Leucine-rich repeat-containing G-protein coupled receptor 5
LPS	Lipopolysaccharide
MSCs	Mesenchymal Stem Cells
NF- κ B	Nuclear Factor kappa B
PRP	Platelet-Rich Plasma
SCFAs	Short-Chain Fatty Acids
SD	Seborrheic Dermatitis
Shh	Sonic Hedgehog
TGF- β	Transforming Growth Factor Beta

1.INTRODUCTION

Systemic biological equilibrium and localised scalp homeostasis are important markers of physiological wellness. The microbial communities of humans are the varied group of microorganisms that live on and inside the host. There is increasing scientific consensus that it is essential for immunological regulation, metabolic functions, and epithelial integrity (Gao et al., 2023; Mahmud et al., 2022). Among other ecological niches, the microbiomes of the skin, scalp, and gut have a significant impact on hair follicle dynamics and dermatological health. Particularly, the gut microbial flora is vital for the control of systemic immunity and the production of micronutrients. The gut and skin communicate through a bidirectional interacting network that links gut flora metabolism to cutaneous and follicular responses (Mahmud et al., 2022; Rios-Carlos et al., 2024). The scalp microbiota, a particular subset of the skin numerous environmental factors impacts the microbiome, such as follicular density, surface pH, humidity, and sebum concentration. Notable microbial taxa that coexist in a complex symbiosis that protects the follicular barrier and prevents pathogen colonisation include *Malassezia restricta*, *Staphylococcus epidermidis*, and *Cutibacterium acnes*. However, when the microbial balance can disrupt the normal hair follicle cycle and cause inflammatory reactions, which are often associated with conditions like AGA and AA (Carrington et al., 2023; Z. Liu & Liu, 2023). According to this

study, there is a link between the microbiomes of the stomach and the scalp that combines immunological and metabolic signals to promote good hair development. Expanding research on the microbiome's function in hair health. This illustrates how an imbalance in the microbiota at any part of the body can result in inflammation and oxidative stress nearby the HF, and alter the composition of sebum (Leung et al., 2023; Zhao et al., 2025a). Additionally, we observe which approaches, for example, target particular microbiome groups. In trichology, probiotics, customised diets, and particular topical treatments are promising. Therefore, this study's aim is to look into the existing body of research on the subject of hair health's microbiome, which focuses on clinical and molecular aspects. The microbiome holds promise for scalp health.

2.The Biology of Hair Follicles and the Hair Development Cycle

A relatively complex part of the epidermis, the HF has the ability to continuously regenerate throughout a person's lifetime. Its numerous interconnected parts, which support the action of the HF, include the root sheaths on the inside and outside, the hair matrix and the DP. The bulge region that includes HFSCs, or stem cells from hair follicles, is what makes it most famous. The intercommunication between these epithelial and mesenchymal components causes hair to be produced. And follow the cycle of regeneration (Chu et al., 2025; W. Deng et al., 2021).

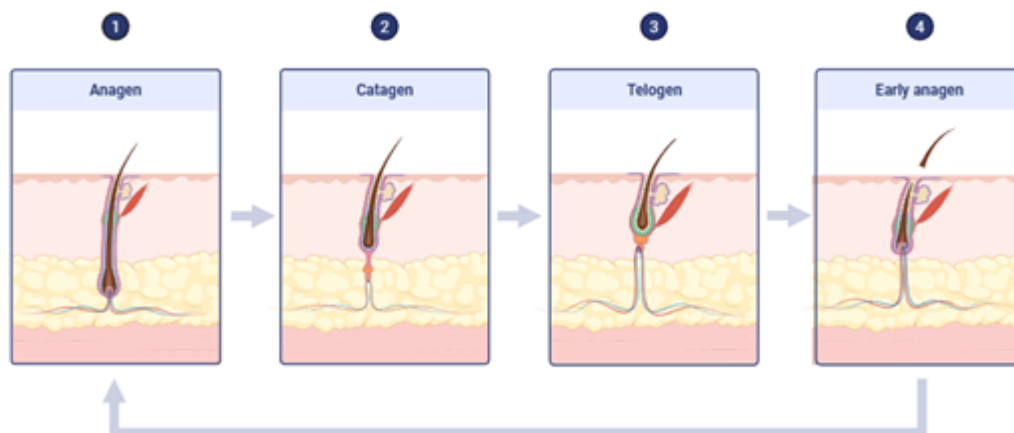


Figure 1: Demonstrating remarkable regeneration capacity, the hair follicle cycle moves through specific stages, converting from anagen to catagen, entering a resting telogen phase, and finally returning to early anagen.(created with biorender) Finally, a robust regenerative substrate, which serves as the basis for healthy hair growth is produced by these interactions

between epithelial and mesenchymal cells that we observe during development to start follicle cycle. The adult follicle exhibits a dynamic hair development cycle, this includes the telogen, catagen, and anagen phases.

2.1. The Hair Follicle Cycle's Dynamics and Signalling Pathways

During anagen, dormant bulge stem cells are activated by dermal papilla signals, which start the hair follicle's fast proliferation and downward development. Once activated, transitory amplifying progenitors differentiate into matrix keratinocytes, proliferating quickly and specializing to create the hair (Lee & Choi, 2024; Xing et al., 2024). This developmental stage is regulated by primary morphogenetic signalling pathways that regulate this including Wnt/ β -catenin, Notch pathways, Shh, BMPs, FGFs. When considered collectively, these pathways are critical for promoting matrix cell growth, activating stem cells, and ensuring healthy hair follicle development (Hamida et al., 2025; Lee & Choi, 2024). The follicle undergoes a tightly controlled process of programmed cell death and structural alteration in its lower portion when it enters the catagen stage. The DP, which is close to the hair's root, becomes squeezed beneath the club hair as the hair bulb retracts (Lee & Choi, 2024). This brief transition step is an involutionary phase that gets the follicle ready to go into a resting state. The follicle is at rest but continues to be metabolically active during the telogen stage. With stem cells from hair follicles in a stage of dormancy which is disturbed by new signalling cues that activate the commencement of. This occurs during the anagen growth Phase (Sivamani et al., 2024; Zhao et al., 2025b).

Recent developments have significantly increased our knowledge of the extrinsic factors governing these cycles. Evidence suggest that regulatory T cells and macrophages act as a key mediator in directing follicular growth and maintaining general hair health. Preserving the immunological privilege of the follicle and stimulating stem cells. Additionally, components of the extracellular matrix, cutaneous fat cells, and vascular endothelial cells are constantly changing. The follicular environment, which in turn affects the change from the regression (catagen) to the growth (anagen) stage (Zhao et al., 2025b). Additionally, these signalling pathways are disrupted by hormonal fluctuations, environmental stresses, and ageing, which results in follicular shrinkage and hair loss.

According to recent developments in regenerative medicine, stem cell-based methods may eventually be able to restore damaged hair follicles or even promote the development of new ones. Studies on hair regrowth. The performance of 3D culture systems has been revealed using methods utilising human hair follicle cells. Additionally, the in vivo follicular simulation of microenvironments that promote regeneration depends on EMTs (Hamida et al., 2025). Additionally, we observe that methods like as bioprinting have been employed in the creation of hair inductive tissue structures by assembling mesenchymal and epithelial

cells in particular configurations that exhibit potential. For the widespread use of hair regeneration treatments (Nanmo et al., 2023).

The HF cycle is actually the product of complex relationships between mesenchymal and epithelial tissues, including cellular connections. It provides the framework for the expansion and regeneration of follicles (Mao et al., 2022). This occurs when these systems function in several common hair conditions. We will see how much therapy for follicle regeneration or neogenesis contributes to the regulation of these biological pathways if they are disrupted in the future.

3.A COMPREHENSIVE OVERVIEW OF HUMAN MICROBIOTA

Fungi, bacteria, viruses and archaea constitute a diverse range of microorganisms that make up the human microbiota. Numerous bodily systems, including the respiratory system, oral cavity, GI tract, and integumentary system, include these microorganisms. These microbes exhibit physiological homeostasis, system-wide immune modulation, metabolic pathway change, and assessment of host response to numerous diseases, all of which are highly significant. Because of host genetics, diet, environment, lifestyle, and age, this microbial community is always changing (Kerk et al., 2018; Xu et al., 2025).

3.1. Elements of the Human Microbiome

3.1.1. Fungi: Commonly residing on the skin, scalp and mucus membranes fungal species like *Candida* and *Malassezia* constitute a significant part of the local microbiome. We see that these fungal communities take role in immunological signalling, lipid metabolism, and maintaining the health of the epidermis. Significant clinical reports connect fungus-induced dysbiosis to skin diseases such dandruff, eczema, and seborrhoeic dermatitis (Mahmud et al., 2022).

3.1.2. Bacteria: Bacteria are considered the most researched part of the microbiota of humans. The gut is largely controlled by phyla like *Firmicutes* and *Bacteroidetes*. By metabolizing food, these groups generate anti-inflammatory SCFAs (eg. Butyrate) and synthesize essential Vitamins B and K. (Abuljadayel, 2025; X. Chen et al., 2023). *Staphylococcus*, *Corynebacterium*, and *Cutibacterium acnes* are the main players that function as protective agents on the skin and scalp by strengthening the epidermal barrier and so preventing the proliferation of dangerous bacteria (Dessinioti & Katsambas, 2024; K. Hou et al., 2022).

3.1.3. Viruses: A diverse collection of bacteriophages, eukaryotic viruses, and endogenous retroviruses make up the human virome. Additionally, it is observed that bacteriophages have two functions: they initiate host

immune responses while simultaneously regulating bacterial populations to preserve microbial diversity. The complex relationships between the virome and host cells and commensal microorganisms play an important part in both health and illness (Leonard et al., 2024)

3.2. Systemic Health and Microbial Ecosystems

3.2.1. Cutaneous Microbiome: The basic biological defence that guards against infections and preserves skin homeostasis is the microbiota. Current bacteria interact with localised immune cells that produce and release amps due to the level of resource competition, which limits inflammation. Various dermatological conditions, including AD, psoriasis, and AV are capable of disrupting the equilibrium of the skin's microbial ecosystem (Haykal et al., 2024; Li et al., 2025; Smith et al., 2025) .

3.2.2. Gastrointestinal Microbiota: Digestion, metabolic health, and immunological development all depend on the gut flora. Gut bacteria improve the intestinal mucosal barrier and lower systemic inflammation by producing SCFAs. IBD, diabetes, obesity, and other neurological conditions are closely linked to dysbiosis in this niche. Additionally, the gut-skin axis has obtained recent focus on critical mechanism where metabolites from the intestinal microbiome directly influence the functional health of the cutaneous barrier (Chai et al., 2024; S. Liu, 2025; Yuan et al., 2025) .

3.2.3. Scalp Microbiome: The distinct layout of hair follicles and increased sebum production distinguish the scalp microbiota, despite some similarities with the broader skin microbiome. The fungi *Staphylococcus* and *Malassezia* are the primary residents. Disorders specific to the scalp, such as dandruff, seborrheic dermatitis, and various types of alopecia, are almost always associated with imbalances in this particular niche (Paul et al., 2025) .

3.3. Immunomodulation within the microbe-host dynamics:

The human immune system operates in close coordination with the resident microbiota. The advancement of the immune system depends on free-living microorganisms because they allow the body's tissue to be recognised as its own and to establish strong defences against pathogens. Microbiological metabolites, especially SCFAs, are critical for keeping up immunological homeostasis because they stimulate the generation of cytokines that reduce inflammation. They also encourage the growth of regulatory T cells (Dong et al., 2023; X. Hou et al., 2022; C. H. Kim, 2023; X. F. Liu et al., 2023) Microbial dysbiosis can lessen systemic inflammation. Changes in the gut microbiota, for example, might set off inflammatory cascades along the gut-skin axis that affect distal locations, cutaneous environments, and follicular damage. Additionally, the restricted immune responses around hair follicles are significantly influenced by the microorganisms on the

scalp, and changes in these responses can result in chronic inflammation and inadequate hair Growth (Paul et al., 2025; Zhao et al., 2025b) .

4. THE IMMUNE-PRIVILEGED NICHE OF THE HF

The HF is a minute regenerating functional unit with immunological advantages, according to recent developments in regenerative biology. Dynamic interactions with a specific population of enrolled and resident immune cells control its development, regeneration, and cyclical changes. Immunological mediators like a macrophage, γ/δ T cells, regulatory T cells, and langerhans cells control the inactivation and quiescence of HFSCS in the follicular niche through complex cytokine and chemokine signalling (Kiselev & Park, 2024) .

Chemokines like CCL20, which attract Tregs to the perifollicular milieu to preserve immunological tolerance, are released by the scalp microbiome, further activating this niche. In addition to maintaining HFSC homeostasis, this intricate immune-microbiome interaction acts as a vital defence against inflammatory imbalance, which is the main cause of many alopecia's. For the follicular function in the setting of regeneration the immune regulation has been essential. Pro-regenerative signaling pathways- specially Shh, FGF and Wnt/ β -catenin cross-talk with immune cells to modulate the inflammatory response and guide tissue redevelopment. Therapeutic therapies such as PRP, stem cell based and microneedling grafts are thought to promote hair growth by co-activating classical signalling cascade and concurrently recalibrating localised immune responses (R. Liu et al., 2024; T. Liu et al., 2020; X. Wang et al., 2016) .

4.1. Experimental Evidence: Immune Modulation in Hair Disorders

Research confirms that immune modulation influences both the pathogeny and intervention of AGA. The study found that HF-MSCS significantly reduced follicular inflammation and promoted hair growth in mice with AGA. This process involves both environmental reprogramming and severe immunosuppression. Unlike direct follicle regeneration methods, HF-MSCS fail to generate cytokines that manage inflammation and restore immune balance, essential for follicular homeostasis (W. Deng et al., 2021; Y. Deng et al., 2023) .

Immune-derived growth factors are necessary for WIHN and tissue repair. These regenerative pathways are triggered by specific cellular interactions within the wound. Specifically, macrophage-derived TNF- α and FGF9 secreted by γ/δ T cells stimulate the Wnt/AKT pathway in LGR5+ HFSCS. Together, these signals increase the cell proliferation and differentiation necessary to form new follicles (Mehta et al., 2025; Rahmani et al., 2020) .

By demonstrating the intricate interactions between the follicular environment, SC activation, and inflammatory resolution, this research establishes immune-microbiome

dynamics as a foundational principle in regenerative trichology.

Table 2: A summary of immunological control in hair follicle health and regeneration

Immune components	Mechanism of action	Effect on hair follicle biology	References
Macrophages	In reaction to microenvironmental stimuli, Wnt ligands and cytokines (TNF- α and Oncostatin M) are released.	Regulate HFSC activation and quiescence; Wnt/AKT signaling, which is triggered by TNF- α , encourages follicle renewal; and inflammatory alopecia is linked to excessive exercise.	(Kiselev & Park, 2024)
Tregs, or regulatory T-cells	The cells are attracted by a microbial-induced alteration in CCL20, produce cytokines, and communicate via Jagged-1/Notch signaling.	Prevent autoimmune attacks on follicles by preserving immunological tolerance and encouraging HFSC differentiation and proliferation.	(Kiselev & Park, 2024)
$\Gamma\delta$ T-cells	Triggers for FGF9 production after injury are Wnt signaling in dermal fibroblasts.	Enhance the capacity for regeneration while stimulating the growth of new hair follicles (wound-induced hair neogenesis).	(Mehta et al., 2025)
Mscs generated from hair follicles	Pro-inflammatory cytokines and lymphocyte infiltration are decreased by immunomodulatory paracrine signaling.	In AA mouse models this effect is the encouragement of regrowth and the restoration of local immunological balance.	(W. Deng et al., 2021)
Commensal microorganisms	Encourage the production of antimicrobial peptides and keratinocyte chemokines, such as CCL20.	Maintain a healthy hair cycle, regulate the follicular immune niche, and recruit protective Treg.	(Kiselev & Park, 2024)
Canonical regenerative signaling (FGF, Shh, Wnt/ β -catenin)	The process is modulated by immune cells, cytokines, and the body's inflammatory state.	It combines proper follicular function with immune system homeostasis, which in turn promotes stem-cell-mediated renewal and enhances results when employing regenerative therapies like PRP and microneedling.	(R. Liu et al., 2024)

5.THE GUT MICROBIOME'S EFFECT ON HAIR HEALTH

Systemic physiology depends on a balanced gut microbiome, which directly impacts dermatological and follicular health. Dominated by Firmicutes, Bacteroidetes, Actinobacteria, and Proteobacteria, this ecosystem regulates immune homeostasis and endocrine signaling. Furthermore, a healthy gut strengthens the mucosal barrier and optimizes cytokine production (Cunningham et al., 2021) . However, a dysbiosis state, described by microbial dysregulation, elevated oxidative stress, and persistent systemic inflammation, correlates with follicular encapsulation and early-onset alopecia.

5.1.The Gut-Skin Axis and Metabolic Signalling

Recent studies highlight a dual-way communication system called the gut-skin axis route allowing gut microbes to influence distant areas like the scalp. Bioactive SCFAS including propionate and butyrate, bile acids, and tryptophan derivatives are examples of microbial metabolites, support hair follicle health by managing immune responses and skin cell growth. SCFAS possess anti-inflammatory properties characterized by their ability to modulate the immune landscape, specifically through the suppression of TNF- α , IL-6 and the enhancement of Treg-mediated pathways in the scalp (Cao et al., 2025a; Jung et al., 2022) .

Beyond immune system modulation, production and absorption of essential micronutrients including folate,

biotin, essential amino acids, and vitamin B12 are aided by gut flora. These substances are essential substrates for keratin production and follicular cell division. Nutrient deficiencies, which are connected to receding hair and reduced anagen phase, might result from disruption of this metabolic equilibrium brought on by antibiotic use, poor diet, or dysbiosis (Cunningham et al., 2021; Mahmud et al., 2022; Zhao et al., 2025b).

Therapeutic potential and endocrine modulation there is proof that the gut microbiome affects hormonal pathways that are essential for hair morphogenesis, particularly those involving cortisol and androgens. By interfering with the hepatic metabolism of sex hormones and possibly increasing the availability of androgens in the system, gut dysbiosis may exacerbate AA. Additionally, the HPA axis and gut microbiome interact to regulate stress responses associated with telogen effluvium and autoimmune-related hair loss (Leung et al., 2023).

Consequently, a lot of microbiome research is currently at its very early stages. Probiotic supplements and dietary modifications may enhance epidermal health, lower systemic inflammation, and restore microbial balance. These benefits are reported to be observed not only in the

area of skin health but also in the body as a whole, including the gut. Certain strains of *Lactobacillus rhamnosus* have been observed to be members in both clinical and laboratory settings. Additionally, *Bifidobacterium longum* possesses antioxidant qualities that shield the follicular environment. When we combine all of these, we find that the gut microbiota is essential in hair. Innovative multimodal therapy approaches prioritise health.

(Asfour et al., 2020; Satheesha Nayak et al., 2017)

6. THE FUNCTION OF THE SCALP MICROBIOME IN HAIR PHYSIOLOGY

The human scalp is a highly specialised cutaneous microenvironment because of its high follicular density, active sebaceous glands, and lipid-rich surface that supports a distinct microbial community. The scalp microbiome is dominated by fungi, especially *Malassezia Spp.*, in addition to bacterial taxa such *Cutibacterium*, *Staphylococcus*, *Corynebacterium*, and *Micrococcus*. To preserve the integrity of the scalp barrier, control sebum metabolism, and stop opportunistic infections from colonising, these microorganisms cohabit in a dynamic symbiotic state (Leung et al., 2023; Smith et al., 2025).

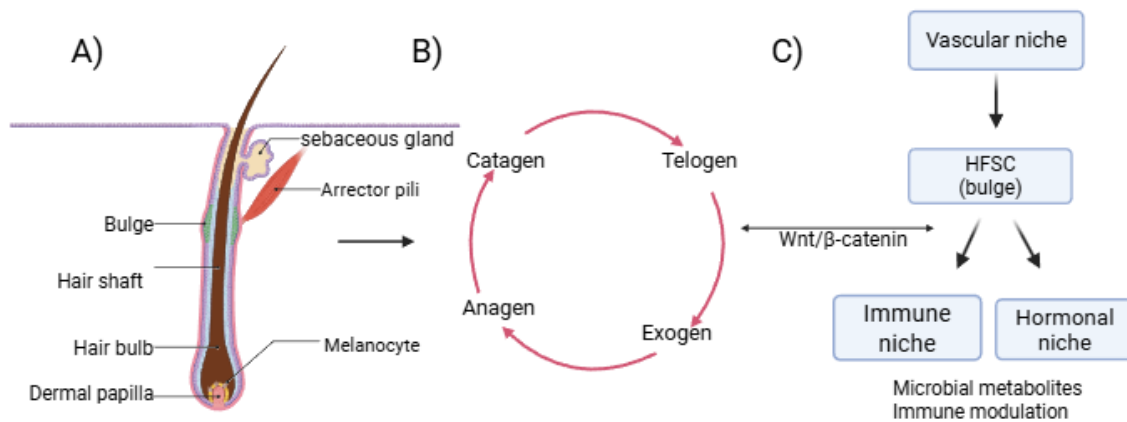


Figure 2: An outline of the HF unit is regulatory pathways. (A) Pilosebaceous unit anatomy. (B) The dynamic cycle of hair growth. (C) Hair follicle stem cells (HFSC) are modulated by microbial metabolites and signalling pathways such as Wnt-β-catenin through vascular, immunological, and hormonal environments. (created with biorender)

6.1. Microbial dysbiosis and follicular homeostasis

Through continuous contact with keratinocytes and sebocytes via pattern-recognition receptors, especially TLRs, a healthy scalp microbiome maintains follicular homeostasis. These signalling pathways promote the creation of host-derived AMPs and control immunological tolerance. An imbalance in these populations known as microbial dysbiosis can produce oxidative stress and inflammatory cascades that interfere with the follicular cycle and may result in hair loss. For instance, the pathophysiology of seborrhoeic dermatitis

and androgenetic alopecia is frequently connected to the depletion of commensal *Staphylococcus epidermidis* and the concurrent proliferation of *Cutibacterium acnes* and *Malassezia restricta*. (ASHWIN GS et al., 2026).

6.2. Microbial Diversity Modulators: Intrinsic and Extrinsic

Examples of inborn host characteristics that interact intricately with external factors such as environmental pollutants, cosmetic use, and hygiene behaviours are age, sex, endocrine state, and sebum production. Together, these factors impact microbial diversity and metabolic

acidophilus supplementation has been reported to help reverse experimentally induced gut dysbiosis, demonstrating the capacity of beneficial microorganisms to modify disturbed microbial environments (Mukilan et al., 2024).

7.1. Systemic Inflammation and Follicular Dynamics

The shift toward an inflammatory state is primarily mediated by the rise of cytokines including IL-6, TNF- α , and IL-1 β , whose systemic concentration increases following gut microbial imbalance. These mediators alter the scalp's immunological response and decrease the activation of HFSCs. Consequently, these long-term inflammatory conditions shorten the anagen phase, induce early catagen, and exacerbate telogen effluvium and androgenetic alopecia. Additionally, we observe that the endotoxin lipopolysaccharide (LPS) and other immune-stimulating toxins of gut origin activate the TLR pathways of follicular keratinocytes, which increases the immune response and induces local oxidative stress. (T. Liu et al., 2020; Ni et al., 2022; Zouboulis et al., 2021)

7.2. Stress Response and Neuroendocrine Regulation

The gut bacteria have a major impact on the HPA axis, the main neuroendocrine mechanism for stress regulation. When our body's stress response system is out of balance, skyrocketing cortisol levels can weaken the scalp's protective barrier, triggering inflammatory hair loss such as alopecia areata. However, there is promising research showing that we can fight back: Probiotics may reduce systemic inflammation, stress and restoring digestive health through dietary changes, ultimately helping to nourish and restore hair follicles (Lu et al., 2024; Zhang et al., 2025).

7.3. Integrated Trichology and Reciprocal Diversity

A recent study that actually examined this topic found a connection between the microbiota of the scalp and the gut. We see a reduction in gut microorganisms in AGA. Reductions in the profusion of *Staphylococcus epidermidis* and *Cutibacterium acnes* often result in a marked loss of microbial diversity across the scalp environment. This system wide-to-local link emphasises the impact of gut health in conserving the equilibrium of the scalp microbial population and density of the hairs (Carrington et al., 2023; Jung et al., 2022; R. Liu et al., 2024).

The gut-to-scalp axis also advocates for an integrated trichology approach that addresses both localised follicular diseases and systemic metabolic problems. Additionally, it is necessary for study in order to analyse the interactions between different microbial habitats. Microbiome based diagnosis could be revolutionised by these investigations. They might also enhance our efforts to maintain healthy hair. In what we observe about these connections, we can also observe that specific medicines result in improved hair health. That could improve the scalp and hair health (H. Chen et al., 2025).

8. MICROBIOME-DRIVEN HAIR DISORDERS: THEIR PATHOPHYSIOLOGY

Emerging data demonstrates that the gut and scalp ecosystems trigger the pathological process of common hair disorders like AGA, AA, and SD. Additionally, note that oxidative stress and localised lipid peroxidation has increased. Notable shift in the relative prevalence of AGA's *Cutibacterium acnes* and *Malassezia restricta*. These metabolic problems then accelerate hair follicular atrophy and induce perifollicular inflammation (Li Pomi et al., 2025; Shi et al., 2025; Suzuki et al., 2021).

Additionally, autoimmunity against hair follicles in alopecia areata is frequently linked to a taxonomic shift to *Corynebacterium* and *Staphylococcus* species. This implies that autoimmunity in the follicular niche may be brought on by specific microbial antigens. The inflammatory response in seborrhoeic dermatitis is exacerbated by *Malassezia*-mediated hydrolysis of sebum lipids into irritating free fatty acids; this maintains an inflammatory state and harms the epidermal barrier (Smith et al., 2025).

Various findings collectively imply that microbial metabolites, biofilm formation, and host microbe immunological cross-talk considerably modify the follicular milieu, which consequently affects the beginning and development of several illnesses. Therefore, targeting microbial imbalances through the strategic use of probiotics, targeted antifungals, or microbiota-modulating medications is an Innovative and evidence-based supplemental methodology for the therapeutic medication of chronic scalp and hair problems.

8.1. Microbial and Lipid Interactions in Dandruff and Seborrhoeic Dermatitis

Dandruff and seborrhoeic dermatitis are chronic inflammatory diseases mostly impacting areas of skin high in sebaceous. They are often associated with the growth of lipophilic yeasts, especially *M. Globosa* and *M. restricta*. Two notable alterations in the microbial environment seen in affected areas are a decrease in major bacterial commensals and a considerable rise in the ratio of *M. Globosa* to *M. Restricta* at follicular apoptotic sites (Liang et al., 2025; Mayser et al., 2024; Tao et al., 2021).

The pathophysiology is mediated by extracellular lipases and phospholipases secreted by *Malassezia* species. These enzymes hydrolyse triglycerides generated from sebum into unsaturated lipids, free fatty acids (FFAs), and other oxidised lipid species. These microbially Produced lipid mediators trigger keratinocytes to start innate immune signalling, endangering the structural integrity of the stratum corneum. This metabolic cascade, which alters the localised pH and electrical resistance of the epidermal barrier, manifests clinically as erythema, scaling, and pruritus (Bitton et al., n.d.).

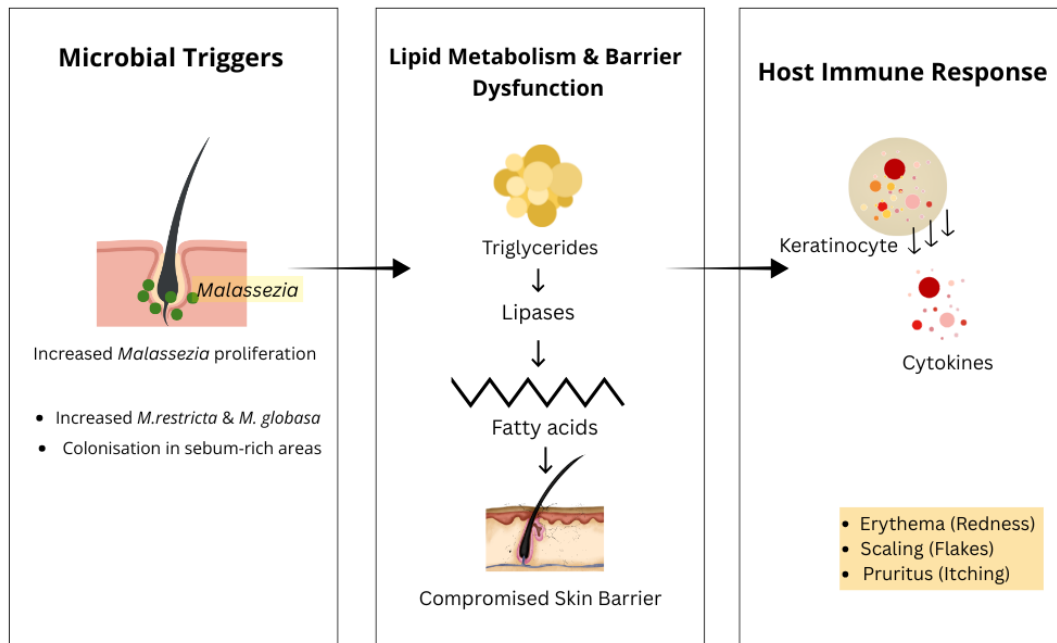


Figure 4. Seborrhoeic dermatitis and dandruff pathophysiology. The microbial-lipid-host interaction is depicted in the diagram, beginning with the spread of *Malassezia* species. Sebum triglycerides are converted into free fatty acids by these fungi using lipases, this disrupts the epidermal barrier and triggers the keratinocytes-derived proinflammatory cytokines. (created with canva)

The host-specific factors that further affect the clinical manifestation of SD and dandruff include the composition of sebum, the condition of the epidermal barrier, and the expression of immunological receptors. The disease's etiology, understood as a complex interplay of commensal bacteria, lipid metabolism, and host immunity, is supported by the success of lipid modulating and antifungal therapies (Suzuki et al., 2021).

8.2.Androgenetic Alopecia (AGA)

Genetically susceptible individuals experience follicular miniaturization, leading to systematic hair loss. The primary cause is aberrant androgen signaling, where 5 α -reductase converts testosterone into potent dihydrotestosterone (DHT) in the follicles (Ntshingila et al., 2023). DHT binds to AR, which are far more abundant in vulnerable scalp follicles. This binding initiates a series of chemical reactions that progressively lengthen the resting phase and shorten the growth phase. Consequently, terminal HF progressively develop into vellus-like, fine, non-pigmented hairs (Y. Deng et al., 2023).

Moreover, recent studies suggest that the localised microbiome may affect perifollicular inflammation and oxidative stress to alter these androgen-driven pathways,

accelerating the process of miniaturisation in affected individuals.

8.2.1.Emerging Mechanisms and AGA's Clinical Dynamics

Recent research has significantly broadened the traditional androgen-centric paradigm by identifying secondary pathways that accelerate follicular shrinkage. Hair Follicle Stem Cell (HFSC) reports that conditions that hinder function include dysregulated Wnt/ β -catenin signalling, persistent oxidative stress, and micro-inflammation in the perifollicular environment. The fact that genetic predisposition at multiple loci, especially those surrounding the AR gene, contributes to the onset and manifestation of the condition demonstrates the polygenic foundation of AGA (de Souza, 2025; Shi et al., 2025).

Women exhibit diffused thinning over the crown, which maintains the frontal hairline, while men typically exhibit temporal recession and apex thinning. The term "female pattern hair loss" Refers to this phenomenon. Although FPHL/AGA is not typically linked to it, it has a significant emotional impact. To widespread health problems, increasing anxiety, extremely low self-esteem, and a substantial loss in health. Regarding both increasing well-being and hair loss (Cuevas-Diaz Duran et al., 2024; Y. Deng et al., 2023).

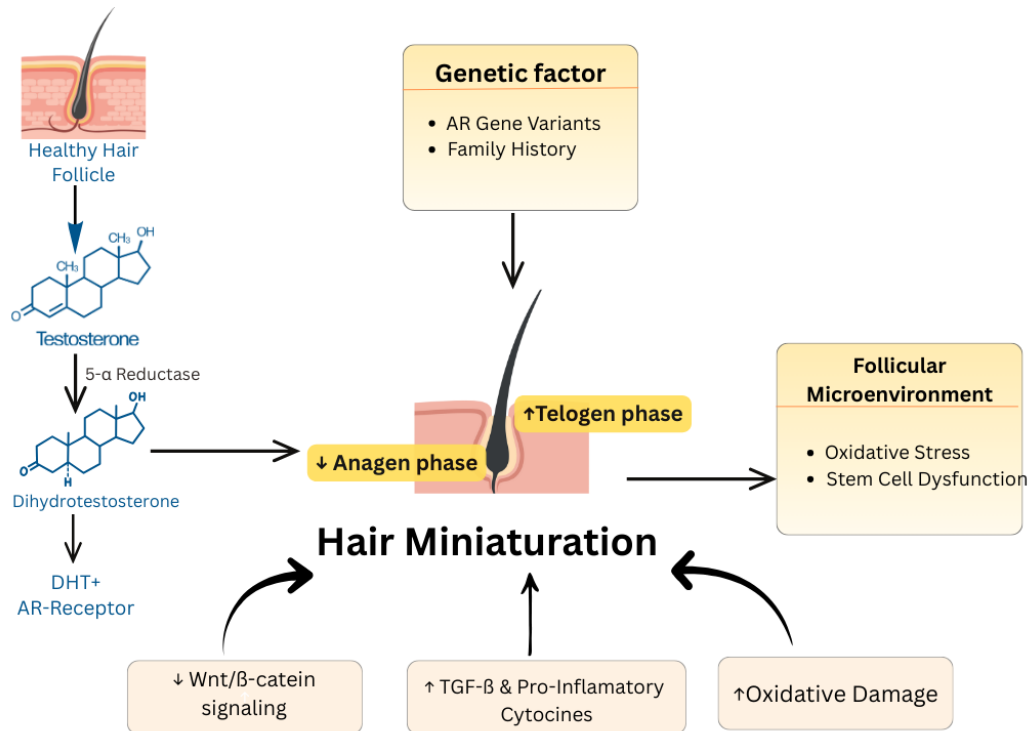


Figure 5. This schematic illustrates how the downregulation of Wnt/ β -catenin pathways, in conjunction with heightened TGF- β and cytokine activity, orchestrates the pathological shift from terminal to vellus hair types. (created with Canva)

AGA's clinical symptoms clearly show sexual dimorphism: female patients have gradual thinning of the crown with a maintained frontal hairline, whereas male patients are more likely to have vertex thinning and bitemporal recession (70). Although AGA has significant psychosocial implications, it is not usually linked to systemic illness have connected increasing low self-esteem, a discernible decline in general life quality, and worry to progressive hair loss. (Al Najjar et al., 2023; Aukerman & Jafferany, 2023) .

The primary objectives of current treatment methods, which primarily involve topical or oral minoxidil and 5 α -reductase inhibitors, are to reduce androgenic activity and regulate the hair cycle. However, recent research indicates a shift toward combinatorial, mechanism-based therapies. These next-generation approaches focus stem

cell preservation, enhance follicular metabolism, and simultaneously target localised inflammation to improve long-term clinical outcomes (Y. Deng et al., 2023; Shi et al., 2025) .

8.3. Microbial Triggers and Inflammatory Dynamics in Scalp Folliculitis

Clinical signs of scalp folliculitis include erythema, pustules, follicular papules, and localised pruritus. It is a complex inflammatory illness affecting the hair follicle complex. It covers many types of sickness, from severe cicatricial alopecia's to superficial infections that do not leave scars. Instead of being merely a temporary surface infection, scalp folliculitis is a complex pathology brought on by immune dysregulation, microbial dysbiosis, and structural alterations in the follicular environment(Starace et al., 2023) .

8.3.1. Fungal and Bacterial Pathogenesis

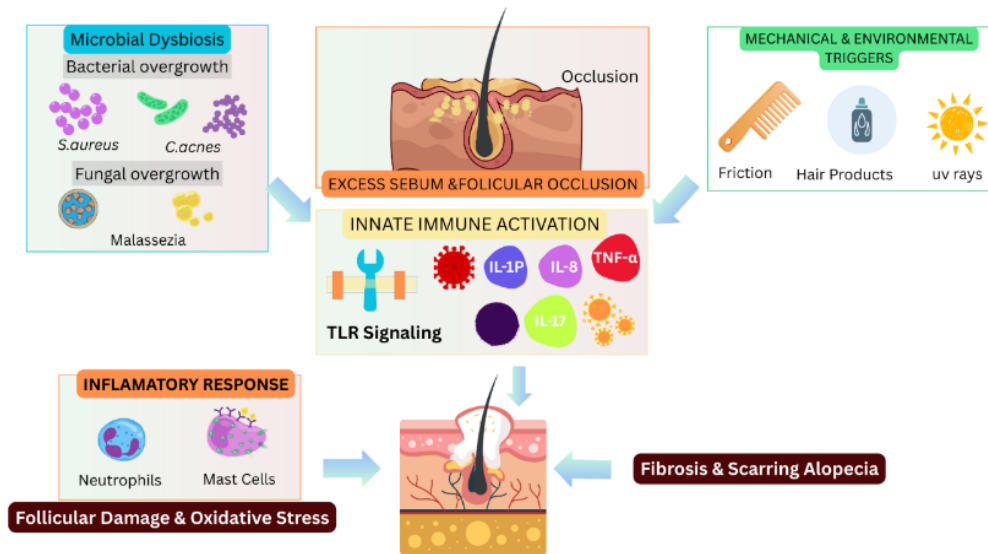


Figure 6: The complex pathophysiology of cicatricial alopecia and follicular destruction. A synergistic "triple threat" mechanism drives the progression towards permanent hair loss: (1) microbial dysbiosis, which is typified by the overgrowth of *S. Aureus*, *C. Acnes*, and *Malassezia*; (2) follicular occlusion, which is made worse by excess sebum; and (3) environmental triggers, which include UV radiation and mechanical friction. TLR-mediated innate immune activation is triggered by these substances. These stimuli provoke the synthesis of an extensive of inflammatory cytokines, notably IL-17, TNF- α , IL-8, and il-1 β . The ensuing neutrophil and mast cell invasion damages follicles and prolongs oxidative stress. This eventually leads to scarring alopecia and irreversible fibrosis. (created with canva)

Staphylococcus aureus continues to be the principal bacterial pathogen linked to scalp folliculitis. By generating toxins, creating biofilms, and continuously colonising follicles, it starts neutrophilic inflammation. The illness may last longer if the host's immune system is strengthened by prolonged exposure to *S. aureus* antigens (Sivori et al., 2024). Furthermore, via triggering innate immune pathways such Toll-like receptor (TLR) signalling, *Cutibacterium acnes* have been connected to the follicular unit is production of proinflammatory cytokines (Hamann et al., 2025). The lot of interest has recently been shown in the pathogenic potential of fungus, especially *Malassezia* Species. Antifungal treatment significantly improves the clinical course of yeast-induced nonscarring folliculitis, which is typically characterised by monomorphic, extremely itchy papules. This emphasises how crucial it is to distinguish between bacterial and fungal origins in order to maximise treatment results. (Chalupeczak & Lipner, 2025; Martinez-Ortega et al., 2024; Shah et al., 2024)

8.3.2. Dysbiosis and Immune Pathways

Scalp dysbiosis is characterised by altered bacterial and fungal diversity. This condition promotes elevated levels of oxidative stress and persistent peri-folliculitis. These microbial alterations may compromise the hair follicle's immunological tolerance, leading to long-term illnesses like Folliculitis Decalvans (Shah et al., 2024). Studies using immunohistochemistry also reveal a rise in cytokines, such as IL-17. Indicating that the aetiology of

the disease depends heavily on Th17-mediated immune mechanisms (T. Liu et al., 2020).

8.3.3. Clinical Development and Cicatricial Results

Clinically, the vertex and occipital regions are typically affected by scalp folliculitis. Additionally, the condition is usually treated, however some more chronic varieties may leave scars. Alopecia and irreversible hair loss. The severe type of folliculitis decalvans is characterised by increasing fibrosis, tufted hair follicles, and recurring inflammatory flares brought on by an immune hypersensitivity to microbial antigens, which ultimately results in scalp folliculitis. Environmental factors and host immunological components are constantly at odds. Microbiological variations. We determine which of these pathways is essential for good health. Both non-scarring and permanent hair loss are preceded by inflammation (Andrade et al., 2025; Ling, 2024; Singh et al., 2025).

9. MODULATION OF THE SCALP MICROBIOME FOR THERAPEUTIC AND COSMETIC PURPOSES

Innovative approaches have been developed in response to interest in microbiome-targeted treatments. Re-establish the scalp microbiome's homeostasis. Probiotics, prebiotics, and postbiotics make up the majority. Used in these processes to improve follicular health and reduce inflammation (Carmona-Cruz et al., 2022; Carrington et al., 2023).

9.1.Probiotics and prebiotics.

Probiotic strains like *L. Plantarum* and *B. Longum* have demonstrated remarkable efficacy in topical treatments that both increase and decrease scalp moisture. Restoring the ideal physiological pH and reducing localised oedema (S. Kim et al., 2024). Undigestible prebiotics, such as inulin found in shampoos and conditioners, also do this. It also keeps skin diseases at bay. Which encourages the development of commensal microbes through colonisation (Xu et al., 2025). Nutraceutical and probiotic interventions may also influence host immune responses through modulation of microbial communities. Recent experimental work has demonstrated beneficial effects of probiotic preparations on physiological outcomes, supporting the broader therapeutic potential of probiotic-based strategies for microbiome-associated conditions (Bak et al., 2024).

9.2.Integrity of Formulation and Postbiotics

The metabolites of probiotic fermentation, known as postbiotics, have strong antioxidant and anti-inflammatory properties that support scalp health. (Dinić et al., 2025). Additionally, the effectiveness of this biotics is sometimes compromised by conventional cosmetic chemicals. We really need your microbiome friendly services in the therapeutic setting. Products that support a healthy scalp ecosystem and those that preserve scalp ecology may be omitted if they are not relevant. Products that maintain a balanced and healthy environment for the scalp may be excluded if they are not applicable. Products that support appropriate scalp microbiota may also be excluded if they are not applicable. Preservatives and surfactants have the potential to upset the sensitive microbial ecosystem (Y. Wang et al., 2023). Moreover, to probiotics, postbiotics bioactive elements like enzymes, SCFAs and cell wall fragments are being utilised increasingly frequently. We are discovering a great deal about their possible medical applications.

Additionally, postbiotics perform better in terms of stability and safety in cosmetic goods than live bacteria. Postbiotic metabolites are said to accomplish this. Within the hair follicle microenvironment, Essential growth factors, notably VEGF and IGF-1, act as a biochemical trigger that catalyse the move from the telogen phase into anagen (Yin et al., 2024).

9.3.Symbiotic Solutions and Bioengineering

Prebiotics and probiotics are examples of symbiotic solutions that have been made possible by advances in bioengineering. The vitality of hair fibres is intended to be increased and scalp stabilisation aided by these compositions through adjustment of the follicle's environment. Together, a paradigm changes in trichology away from generic therapies and toward evidence based, microbiome-focused dermatology is marked by these developments (S. Kim et al., 2024; Smith et al., 2025).

10.IMPACT OF DIET, LIFESTYLE AND ENVIRONMENTAL TRIGGERS ON HAIR MICROBIOME

Follicle persistence and hair vitality are influenced by the microbiota of the scalp and gut, which is effect by environmental variables and lifestyle. Food is the primary modulator; The intake of omega-3 fatty acids, polyphenols and vital vitamins through the diet serves to mitigate systemic inflammatory markers and foster a robust microbial environment. Conversely, intestinal dysbiosis, which is associated with hormonal abnormalities and systemic oxidative stress, was caused by meals high in glycaemic index or saturated fat (Raza et al., 2025).

10.1.Neuroendocrine Regulation and Stress

The HPA axis is set off by psychological stress. These unleash a chain reaction that shifts the gut microbiome and drives up cortisol throughout the body. These neuroendocrine alterations frequently increase the risk of inflammatory hair loss by upsetting the hair follicle cycle and endangering the scalp barrier's integrity (Ivanova & Buzova, 2025).

10.2.Cosmetic Stressors and Environmental Exposure

The microbial colonisation and the lipidome of the scalp are impacted by reactive oxygen species produced by exterior surrounding stressors such as particle air pollution, UV radiation, and heavy metals. Common cosmetic procedures, like as harsh cleaners, chemical colouring, and excessive heat style, can also significantly reduce the range of bacteria on the scalp. Clinically, these can show up as different types of seborrhoea, dandruff, and alopecia (Leung et al., 2023; Paul et al., 2025).

Synthetic preservatives like parabens and surfactants like sodium lauryl sulphate (SLS), which may lower commensal populations of *Staphylococcus epidermidis*, are widely used in hair care issues today. This in turn encourages the establishment of harmful *Malassezia* and *Candida acnes* species. Additionally, we see that the cosmetics business has Microbiota-friendly certifications that cover physiological pH (usually 5.5) and ecological variety of the scalp (Ivanova & Buzova, 2025; Wojciechowska & Dos Santos Szewczyk, 2025).

10.3.Moving Towards a Comprehensive Strategy for Follicular Homeostasis

Additionally, we have a large-scale method that examines the homeostasis of the gut skin scalp axis. This involves controlling stress, using microbiome friendly hair care products, and maintaining a balanced diet that includes probiotics and antioxidants. These integrative techniques aim to maintain the diversity of microbes and the long-term homeostasis of HF (Naliyadhara et al., 2023; Pessemier et al., 2021).

11.PROSPECTS FOR THE FUTURE: MULTI-OMICS INTEGRATION AND PRECISION TRICHOLOGY

Trichology is changing due to developments in multi-omics technology. Future studies incorporating targeted hair care treatments and individualised diagnostics are made possible by the use of multi-omics in trichology. It provides a thorough examination of microbial genomes, Host-microbe interactions, and metabolic processes. We have functional knowledge in metagenomic and metabolomic research. When it comes to identifying scalp flora, it goes beyond the conventional taxonomic framework. Particular microbial genetic groups linked to lipid metabolism, keratin breakdown, and antioxidative stress treatment (Leung et al., 2023; Yu et al., 2025)

11.1. Predictive Diagnostics and Machine Learning

The development of predictive algorithms that can recognise minute microbial fingerprints linked to follicular illnesses is becoming easier because to the combination of bioinformatics and machine learning (Sun et al., 2023). This is enabling the development of precision trichology, a medical speciality that uses microbial data to develop customised treatment plans based specific microbial profile and physiological reactivity of each patient (Cao et al., 2025b). Furthermore, the identification of certain microbial markers may greatly benefit in the early detection of dysbiosis, which causes hair loss. Improving Present Dermatological Methods (Z. Liu & Liu, 2023).

Additionally, the clinical use of scalp microbiome testing will determine how hair loss is treated. Dysbiosis patterns are identified using a non-invasive scalp swab and 16S rRNA sequencing prior to the onset of clinical hair thinning (Xu et al., 2025). According to the Microbial Index for Hair Loss, doctors can target the follicular environment in high-risk patients to stop follicles from stabilising. Customised prebiotic serums are among the interventions (Jung et al., 2022).

11.2 Multidisciplinary Paths

To use microbiome research to dermatology and useful application systems. The importance of biology and microbiology in research will increase. We look at the stomach the norm will shift as a systems-based approach to problems of the skin and scalp gains popularity. For developing a healthy scalp and growing new hair. (Gómez-Arias et al., 2024; Z. Liu & Liu, 2023).

CONCLUSION

According to a study, the microbiome of humans serves an essential function in controlling the biology of HF and preserving the health of the scalp. We find that follicular signalling, immunological response, and metabolic pathways all of which control the hair follicle cycle are affected by the skin, scalp, and intestinal microbiota. The idea of the microbial axis of the gut-scalp is also presented, which suggests that the system-wide microbial population from this passage is malfunctioning, which impacts follicular homeostasis and contributes to scalp inflammation. Many hair disorders, such as AGA, AA, seborrhoeic dermatitis, and scalp folliculitis, are linked to

the disturbance of microbial equilibrium in the gut or the scalp environment. This study, which was primarily dermatological in nature, is currently being examined from a broader systemic and microbiome-centered perspective. Probiotics, prebiotics, dietary changes, and microbiome-friendly cosmetic formulations are examples of treatments based on microbiomes that may be improved follicular health and restore microbial equilibrium. Combining multi-omics techniques with clinical research is crucial to achieving sustained hair growth and individualised scalp care.

REFERENCES

- Abuljadayel, D. A. (2025). The Human Microbiome: Guardian of Health with a Spotlight on the Blood Microbiome and Disease Prevention. In *Journal of Applied Hematology* (Vol. 16, Number 3, pp. 187–211). Wolters Kluwer Medknow Publications. https://doi.org/10.4103/joah.joah_80_25
- Al Najjar, O. A., Alkhars, M. A., Al Molhim, S. F., AlAjmi, M. S., Alhafith, A. A., Al Najjar, M. A., & AlMaqhawi, A. (2023). The Impact of Androgenic Alopecia on the Quality of Life of Male Individuals: A Cross-Sectional Study. *Cureus*. <https://doi.org/10.7759/cureus.47760>
- Andrade, A. G. B. F., Scuotto, C. R. C., & Da Silva, D. L. F. (2025). Refractory Folliculitis Decalvans: New Therapeutic Horizons? *International Journal of Trichology*, 17(1), 66–68. https://doi.org/10.4103/ijt.ijt_83_23
- Asfour, L., Trautt, E., & Harries, M. J. (2020). Folliculitis decalvans in the era of antibiotic resistance: Microbiology and antibiotic sensitivities in a tertiary hair clinic. In *International Journal of Trichology* (Vol. 12, Number 4, pp. 193–194). Wolters Kluwer Medknow Publications. https://doi.org/10.4103/ijt.ijt_98_20
- ASHWIN GS, Dr BALAMURUGAN N, Dr HIRTHIK ROSHAN, Dr KARMUGILAN S, Dr VENUVAIDESH CHENGA REDDY, & PARTHASARATHY S. (2026). Role of skin microbiome and exosomes in Hair regeneration and disorders in diseases like Alopecia, Acne: A comprehensive review. *International Journal of Web of Multidisciplinary Studies*, 3(2), 8–28. <https://doi.org/10.71366/ijwos03022606824>
- Aukerman, E. L., & Jafferany, M. (2023). The psychological consequences of androgenetic alopecia: A systematic review. In *Journal of Cosmetic Dermatology* (Vol. 22, Number 1, pp. 89–95). John Wiley and Sons Inc. <https://doi.org/10.1111/jocd.14983>
- B. Alshalloob, H., A. Almarshoud, G., A. Alamari, E., A. Alomari, A., M. Albelowi, L., S. AlQifari, H., Khalid Z. Alghuyaythat, W., S. Alharbi, W., & Alajlan, A. (2025). The Gut-Scalp Axis: A Systematic Review of Dietary Interventions on Microbiome Dysbiosis in Scalp Disorders. *Journal of Pioneering Medical Sciences*, 14(10), 9–21. <https://doi.org/10.47310/jpms2025141002>

- Bak, S. G., Chandimali, N., Park, E. H., Lim, H. J., Won, Y. S., Kwon, H. S., Lee, N., Oh, H., Yun, S. I., Park, S. I., & Lee, S. J. (2024). Beneficial effects of probiotics derived from *Inonotus obliquus* on menopausal symptoms in ovariectomized mice. *Current Topics in Nutraceutical Research*, 22(4), 1213–1219. <https://doi.org/10.37290/ctnr2641-452X.22:1213-1219>
- Bitton, A., Idkowiak-Baldys, J., Bouslimani, A., Hsi, E., Wang, C., Paturi, J., Chen, Y., Clavaud, C., & Baalbaki, N. (n.d.). *If Malassezia wasn't the only determining factor in dandruff: the role of scalp bacterial profile and ethnicity*.
- Cao, X., Lu, M., Li, N., Cai, L., Wang, Y., & Zhao, Y. (2025a). Emerging biomedical engineering strategies for hair follicle regeneration. In *Bioactive Materials* (Vol. 53, pp. 84–113). KeAi Communications Co. <https://doi.org/10.1016/j.bioactmat.2025.06.051>
- Cao, X., Lu, M., Li, N., Cai, L., Wang, Y., & Zhao, Y. (2025b). Emerging biomedical engineering strategies for hair follicle regeneration. In *Bioactive Materials* (Vol. 53, pp. 84–113). KeAi Communications Co. <https://doi.org/10.1016/j.bioactmat.2025.06.051>
- Carmona-Cruz, S., Orozco-Covarrubias, L., & Sáez-de-Ocariz, M. (2022). The Human Skin Microbiome in Selected Cutaneous Diseases. In *Frontiers in Cellular and Infection Microbiology* (Vol. 12). Frontiers Media S.A. <https://doi.org/10.3389/fcimb.2022.834135>
- Carrington, A. E., Maloh, J., Nong, Y., Agbai, O. N., Bodemer, A. A., & Sivamani, R. K. (2023). The Gut and Skin Microbiome in Alopecia: Associations and Interventions. *Journal of Clinical and Aesthetic Dermatology*, 16(10), 59–64.
- Chai, J., Zhuang, Y., Cui, K., Bi, Y., & Zhang, N. (2024). Metagenomics reveals the temporal dynamics of the rumen resistome and microbiome in goat kids. *Microbiome*, 12(1). <https://doi.org/10.1186/s40168-023-01733-5>
- Chalupczak, N. V., & Lipner, S. R. (2025). Malassezia Folliculitis: An Underdiagnosed Mimicker of Acneiform Eruptions. In *Journal of Fungi* (Vol. 11, Number 9). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/jof11090662>
- Chen, H., Luo, W., Guo, Z., Li, Z., Feng, J., Cao, S., Wang, Q., Gu, Z., Krutmann, J., Wang, J., Han, L., Guo, Y., & Xia, J. (2025). *Integrative Multi-omics Deciphers the Assembly Rules of the Human Skin Microbiome and Highlights Lipid-Mediated Niche Partitioning*. <https://doi.org/10.1101/2025.09.04.674196>
- Chen, X., Zhang, H., Ren, S., Ding, Y., Remex, N. S., Bhuiyan, M. S., Qu, J., & Tang, X. (2023). Gut microbiota and microbiota-derived metabolites in cardiovascular diseases. In *Chinese Medical Journal* (Vol. 136, Number 19, pp. 2269–2284). Lippincott Williams and Wilkins. <https://doi.org/10.1097/CM9.0000000000002206>
- Chu, X., Zhou, Z., Qian, X., Shen, H., Cheng, H., & Zhang, J. (2025). Functional regeneration strategies of hair follicles: advances and challenges. In *Stem Cell Research and Therapy* (Vol. 16, Number 1). BioMed Central Ltd. <https://doi.org/10.1186/s13287-025-04210-y>
- Cuevas-Diaz Duran, R., Martinez-Ledesma, E., Garcia-Garcia, M., Bajo Gauzin, D., Sarro-Ramírez, A., Gonzalez-Carrillo, C., Rodríguez-Sardin, D., Fuentes, A., & Cardenas-Lopez, A. (2024). The Biology and Genomics of Human Hair Follicles: A Focus on Androgenetic Alopecia. In *International Journal of Molecular Sciences* (Vol. 25, Number 5). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/ijms25052542>
- Cunningham, A. L., Stephens, J. W., & Harris, D. A. (2021). Gut microbiota influence in type 2 diabetes mellitus (T2DM). In *Gut Pathogens* (Vol. 13, Number 1). BioMed Central Ltd. <https://doi.org/10.1186/s13099-021-00446-0>
- de Souza, G. T. (2025). Genetic Insights into Acne, Androgenetic Alopecia, and Alopecia Areata: Implications for Mechanisms and Precision Dermatology. In *Cosmetics* (Vol. 12, Number 5). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/cosmetics12050228>
- Deng, W., Zhang, Y., Wang, W., Song, A., Mukama, O., Huang, J., Han, X., Deng, S., Lin, Z., Habimana, J. du D., Huang, R., Peng, K., Ni, B., Zhang, S., Yan, X., Li, J., Wu, L. P., & Li, Z. (2021). Hair follicle-derived mesenchymal stem cells decrease alopecia areata mouse hair loss and reduce inflammation around the hair follicle. *Stem Cell Research and Therapy*, 12(1). <https://doi.org/10.1186/s13287-021-02614-0>
- Deng, Y., Wang, M., He, Y., Liu, F., Chen, L., & Xiong, X. (2023). Cellular Senescence: Ageing and Androgenetic Alopecia. In *Dermatology* (Vol. 239, Number 4, pp. 533–541). S. Karger AG. <https://doi.org/10.1159/000530681>
- Dessinioti, C., & Katsambas, A. (2024). The Microbiome and Acne: Perspectives for Treatment. In *Dermatology and Therapy* (Vol. 14, Number 1, pp. 31–44). Adis. <https://doi.org/10.1007/s13555-023-01079-8>
- Ding, S., Wang, H., Xu, B., Shu, L., Tang, J., Li, H., Shen, Y., & Zhu, J. (2024). Modulation of gut microbiota by xylo-oligosaccharides helps gestational diabetes mellitus patients with intrahepatic cholestasis of pregnancy. *Current Topics in Nutraceutical Research*, 22(2), 582–586. <https://doi.org/10.37290/ctnr2641-452X.22:582-586>
- Dinić, M., Gonzalez, T., Caridad Hernandez, M., Radojević, D., Fernandez, L., Golić, N., & Pastar, I. (2025). Postbiotics as microbial-derived therapeutics for

- wound healing disorders: from molecular mechanisms to future application. In *Cell Communication and Signaling* (Vol. 23, Number 1). BioMed Central Ltd. <https://doi.org/10.1186/s12964-025-02494-4>
- Dong, Y., Zhang, K., Wei, J., Ding, Y., Wang, X., Hou, H., Wu, J., Liu, T., Wang, B., & Cao, H. (2023). Gut microbiota-derived short-chain fatty acids regulate gastrointestinal tumor immunity: a novel therapeutic strategy? In *Frontiers in Immunology* (Vol. 14). Frontiers Media S.A. <https://doi.org/10.3389/fimmu.2023.1158200>
- Fang, X., Wang, Y., Wei, H., & Huang, Y. (2025). Precision Microbiome: A New Era of Targeted Therapy with Core Probiotics. *Research*, 8. <https://doi.org/10.34133/research.0658>
- Gao, T., Wang, X., Li, Y., & Ren, F. (2023). The Role of Probiotics in Skin Health and Related Gut–Skin Axis: A Review. In *Nutrients* (Vol. 15, Number 14). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/nu15143123>
- Gómez-Arias, P. J., Gay-Mimbrera, J., Rivera-Ruiz, I., Aguilar-Luque, M., Juan-Cencerrado, M., Mochón-Jiménez, C., Gómez-García, F., Sánchez-González, S., Ortega-Hernández, A., Gómez-Garre, D., Parra-Peralbo, E., Isla-Tejera, B., & Ruano, J. (2024). Association Between Scalp Microbiota Imbalance, Disease Severity, and Systemic Inflammatory Markers in Alopecia Areata. *Dermatology and Therapy*, 14(11), 2971–2986. <https://doi.org/10.1007/s13555-024-01281-2>
- Grimshaw, S. G., Smith, A. M., Arnold, D. S., Xu, E., Hoptroff, M., & Murphy, B. (2019). The diversity and abundance of fungi and bacteria on the healthy and dandruff affected human scalp. *PLoS ONE*, 14(12). <https://doi.org/10.1371/journal.pone.0225796>
- Hamann, T., Brüggemann, H., Feidenhansl, C., Ruci, E., Gallinger, J., Gallinat, S., & Hüpeden, J. (2025). Distinct Intraspecies Variation of Cutibacterium acnes and Staphylococcus epidermidis in Acne Vulgaris and Healthy Skin. *Microorganisms*, 13(2). <https://doi.org/10.3390/microorganisms13020299>
- Hamida, O. Ben, Kim, M. K., Sung, Y. K., Kim, M. K., & Kwack, M. H. (2025). Hair Regeneration Methods Using Cells Derived from Human Hair Follicles and Challenges to Overcome. In *Cells* (Vol. 14, Number 1). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/cells14010007>
- Haykal, D., Cartier, H., & Dréno, B. (2024). Dermatological Health in the Light of Skin Microbiome Evolution. In *Journal of Cosmetic Dermatology* (Vol. 23, Number 12, pp. 3836–3846). John Wiley and Sons Inc. <https://doi.org/10.1111/jocd.16557>
- Hou, K., Wu, Z. X., Chen, X. Y., Wang, J. Q., Zhang, D., Xiao, C., Zhu, D., Koya, J. B., Wei, L., Li, J., & Chen, Z. S. (2022). Microbiota in health and diseases. In *Signal Transduction and Targeted Therapy* (Vol. 7, Number 1). Springer Nature. <https://doi.org/10.1038/s41392-022-00974-4>
- Hou, X., Zheng, Z., Wei, J., & Zhao, L. (2022). Effects of gut microbiota on immune responses and immunotherapy in colorectal cancer. In *Frontiers in Immunology* (Vol. 13). Frontiers Media S.A. <https://doi.org/10.3389/fimmu.2022.1030745>
- Ivanova, A., & Buzova, V. (2025). A novel enzymatic approach for a targeted fungal growth inhibition. *BMC Microbiology*, 25(1). <https://doi.org/10.1186/s12866-025-04453-y>
- Jung, D. R., Yoo, H. Y., Kim, M. J., Singh, V., Park, S. H., Jeong, M., Park, B. J., & Shin, J. H. (2022). Comparative analysis of scalp and gut microbiome in androgenetic alopecia: A Korean cross-sectional study. *Frontiers in Microbiology*, 13. <https://doi.org/10.3389/fmicb.2022.1076242>
- Kerk, S. K., Lai, H. Y., Sze, S. K., Ng, K. W., Schmidtchen, A., & Adav, S. S. (2018). Bacteria display differential growth and adhesion characteristics on human hair shafts. *Frontiers in Microbiology*, 9(SEP). <https://doi.org/10.3389/fmicb.2018.02145>
- Kim, C. H. (2023). Complex regulatory effects of gut microbial short-chain fatty acids on immune tolerance and autoimmunity. In *Cellular and Molecular Immunology* (Vol. 20, Number 4, pp. 341–350). Springer Nature. <https://doi.org/10.1038/s41423-023-00987-1>
- Kim, S., Suh, D. H., Lee, S., Kim, H. S., Cho, S. H., & Woo, Y. R. (2024). Associations Between Skin Microbiome and Metabolome in the Pathogenesis of Atopic Dermatitis Patients With Scalp Involvement. *Allergy, Asthma and Immunology Research*, 16(6), 668–681. <https://doi.org/10.4168/aaair.2024.16.6.668>
- Kiselev, A., & Park, S. (2024). Immune niches for hair follicle development and homeostasis. In *Frontiers in Physiology* (Vol. 15). Frontiers Media SA. <https://doi.org/10.3389/fphys.2024.1397067>
- Lee, J. H., & Choi, S. (2024). Deciphering the molecular mechanisms of stem cell dynamics in hair follicle regeneration. In *Experimental and Molecular Medicine* (Vol. 56, Number 1, pp. 110–117). Springer Nature. <https://doi.org/10.1038/s12276-023-01151-5>
- Leonard, S., Montanaro, F., Leopold, Z., Helstrom, E., Abbosh, P., Fulmes, A., Correa, A., Barata, P., Nizam, A., Weight, C., & Bukavina, L. (2024). Microbiome in RCC – A systematic review of the literature. *Kidney Cancer*, 8(1), 158–170. <https://doi.org/10.1177/24684570241292246>
- Leung, M. H. Y., Tong, X., Shen, Z., Du, S., Bastien, P., Appenzeller, B. M. R., Betts, R. J., Mezzache, S., Bourokba, N., Cavusoglu, N., Aguilar, L., Misra, N., Clavaud, C., & Lee, P. K. H. (2023). Skin microbiome differentiates into distinct cutotypes with unique

metabolic functions upon exposure to polycyclic aromatic hydrocarbons. *Microbiome*, 11(1). <https://doi.org/10.1186/s40168-023-01564-4>

Li Pomi, F., Gammeri, L., Borgia, F., Di Gioacchino, M., & Gangemi, S. (2025). Oxidative Stress and Skin Diseases: The Role of Lipid Peroxidation. In *Antioxidants* (Vol. 14, Number 5). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/antiox14050555>

Li, Z., Zhang, J., Zhang, Y., Chen, H., & Bao, Y. (2025). Skin Microbiome in Health and Disease: Mechanisms and Emerging Therapeutic Strategies. In *Clinical, Cosmetic and Investigational Dermatology* (Vol. 18, pp. 3443–3455). Dove Medical Press Ltd. <https://doi.org/10.2147/CCID.S571984>

Liang, B., Pu, M., Xu, Y. N., Li, Y., Sun, J. N., Zhu, Y., Doraiswamy, C., Dadd, T., & Chu, C. C. (2025). Dandruff scalp microbiome exhibits flake severity and sex-related differences. *British Journal of Dermatology*, 193, ii32–ii39. <https://doi.org/10.1093/bjd/ljaf099>

Ling, K. (2024). *Clinical Presentation and Pathophysiology of Folliculitis Decalvans and its Complications*. <https://doi.org/10.35248/2167-0951.24.14.251>

Liu, R., Yu, Y., Wang, Q., Zhao, Q., Yao, Y., Sun, M., Zhuang, J., Sun, C., & Qi, Y. (2024). Interactions between hedgehog signaling pathway and the complex tumor microenvironment in breast cancer: current knowledge and therapeutic promises. In *Cell Communication and Signaling* (Vol. 22, Number 1). BioMed Central Ltd. <https://doi.org/10.1186/s12964-024-01812-6>

Liu, S. (2025). Mechanisms of gut microbiota in host fat deposition: metabolites, signaling pathways, and translational applications. In *Frontiers in Microbiology* (Vol. 16). Frontiers Media S.A. <https://doi.org/10.3389/fmicb.2025.1675155>

Liu, T., Li, S., Ying, S., Tang, S., Ding, Y., Li, Y., Qiao, J., & Fang, H. (2020). The IL-23/IL-17 Pathway in Inflammatory Skin Diseases: From Bench to Bedside. In *Frontiers in Immunology* (Vol. 11). Frontiers Media S.A. <https://doi.org/10.3389/fimmu.2020.594735>

Liu, X. F., Shao, J. H., Liao, Y. T., Wang, L. N., Jia, Y., Dong, P. J., Liu, Z. Z., He, D. D., Li, C., & Zhang, X. (2023). Regulation of short-chain fatty acids in the immune system. In *Frontiers in Immunology* (Vol. 14). Frontiers Media S.A. <https://doi.org/10.3389/fimmu.2023.1186892>

Liu, Z., & Liu, X. (2023). Gut microbiome, metabolome and alopecia areata. In *Frontiers in Microbiology* (Vol. 14). Frontiers Media S.A. <https://doi.org/10.3389/fmicb.2023.1281660>

Lu, S., Zhao, Q., Guan, Y., Sun, Z., Li, W., Guo, S., & Zhang, A. (2024). The communication mechanism of the gut-brain axis and its effect on central nervous system diseases: A systematic review. In *Biomedicine and Pharmacotherapy* (Vol. 178). Elsevier Masson s.r.l. <https://doi.org/10.1016/j.biopha.2024.117207>

Mahmud, M. R., Akter, S., Tamanna, S. K., Mazumder, L., Esti, I. Z., Banerjee, S., Akter, S., Hasan, M. R., Acharjee, M., Hossain, M. S., & Pirttilä, A. M. (2022). Impact of gut microbiome on skin health: gut-skin axis observed through the lenses of therapeutics and skin diseases. In *Gut Microbes* (Vol. 14, Number 1). Taylor and Francis Ltd. <https://doi.org/10.1080/19490976.2022.2096995>

Maître, M., Baradat, S., Froliger, M., Turlier, V., Simcic-Mori, A., Gravier, E., Génies, C., Lauze, C., Huyghe, C., Noustens, A., Alvarez-Georges, S., Marinescu, R., Reygagne, P., Bessou-Touya, S., Mengeaud, V., & Duplan, H. (2025). Scalp Microbiome Dynamics Can Contribute to the Clinical Effect of a Novel Antiseborrheic Dermatitis Shampoo Containing Patented Antifungal Actives: A Randomized Controlled Study. *Dermatology and Therapy*, 15(8), 2077–2097. <https://doi.org/10.1007/s13555-025-01408-z>

Mao, M. Q., Jing, J., Miao, Y. J., & Lv, Z. F. (2022). Epithelial-Mesenchymal Interaction in Hair Regeneration and Skin Wound Healing. In *Frontiers in Medicine* (Vol. 9). Frontiers Media S.A. <https://doi.org/10.3389/fmed.2022.863786>

Martínez-Ortega, J. I., Mut Quej, J. E., & Franco González, S. (2024). Malassezia Folliculitis: Pathogenesis and Diagnostic Challenges. *Cureus*. <https://doi.org/10.7759/cureus.73429>

Mayser, P., Genrich, F., Meunier, L., & Nordzike, S. (2024). Scalp Microbiome and Dandruff—Exploring Novel Biobased Esters. In *Cosmetics* (Vol. 11, Number 5). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/cosmetics11050174>

Mehta, A., Motavaf, M., Raza, D., McLure, A. J., Osei-Opare, K. D., Bordone, L. A., & Gru, A. A. (2025). Revolutionary Approaches to Hair Regrowth: Follicle Neogenesis, Wnt/β-Catenin Signaling, and Emerging Therapies. In *Cells* (Vol. 14, Number 11). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/cells14110779>

Mim, M. F., Sikder, M. H., Chowdhury, M. Z. H., Bhuiyan, A. U. A., Zinan, N., & Islam, S. M. N. (2024). The dynamic relationship between skin microbiomes and personal care products: A comprehensive review. In *Heliyon* (Vol. 10, Number 14). Elsevier Ltd. <https://doi.org/10.1016/j.heliyon.2024.e34549>

Mukilan, M., Antony Mathew, M. T., Yaswanth, S., & Mallikarjun, V. (2024). Role of probiotic strain *Lactobacillus acidophilus* in the reversal of gut dysbiosis

- induced brain cognitive decline. *Journal of Experimental Biology and Agricultural Sciences*, 12(1), 36–48. [https://doi.org/10.18006/2024.12\(1\).36.48](https://doi.org/10.18006/2024.12(1).36.48)
- Naliyadhara, N., Kumar, A., Kumar Gangwar, S., Nair Devanarayanan, T., Hegde, M., Alqahtani, M. S., Abbas, M., Sethi, G., & Kunnumakara, A. (2023). Interplay of dietary antioxidants and gut microbiome in human health: What has been learnt thus far? In *Journal of Functional Foods* (Vol. 100). Elsevier Ltd. <https://doi.org/10.1016/j.jff.2022.105365>
- Nanmo, A., Yan, L., Asaba, T., Wan, L., Kageyama, T., & Fukuda, J. (2023). Bioprinting of hair follicle germs for hair regenerative medicine. *Acta Biomaterialia*, 165, 50–59. <https://doi.org/10.1016/j.actbio.2022.06.021>
- Ni, Q., Zhang, P., Li, Q., & Han, Z. (2022). Oxidative Stress and Gut Microbiome in Inflammatory Skin Diseases. In *Frontiers in Cell and Developmental Biology* (Vol. 10). Frontiers Media S.A. <https://doi.org/10.3389/fcell.2022.849985>
- Ntshingila, S., Oputu, O., Arowolo, A. T., & Khumalo, N. P. (2023). Androgenetic alopecia: An update. In *JAAD International* (Vol. 13, pp. 150–158). Elsevier B.V. <https://doi.org/10.1016/j.jdin.2023.07.005>
- Paul, J. K., Azmal, M., Talukder, O. F., Haque, A. S. N. B., Meem, M., & Ghosh, A. (2025). Unlocking the secrets of the hair microbiome: From scalp health to therapeutic advances. In *Microbe (Netherlands)* (Vol. 7). Elsevier B.V. <https://doi.org/10.1016/j.microb.2025.100353>
- Pessemier, B. De, Grine, L., Debaere, M., Maes, A., Paetzold, B., & Callewaert, C. (2021). Gut–skin axis: Current knowledge of the interrelationship between microbial dysbiosis and skin conditions. In *Microorganisms* (Vol. 9, Number 2, pp. 1–33). MDPI AG. <https://doi.org/10.3390/microorganisms9020353>
- Rahmani, W., Sinha, S., & Biernaskie, J. (2020). Immune modulation of hair follicle regeneration. In *npj Regenerative Medicine* (Vol. 5, Number 1). Nature Research. <https://doi.org/10.1038/s41536-020-0095-2>
- Raza, A., Khare, T., Zhang, X., Rahman, M. M., Hussain, M., Gill, S. S., Chen, Z. H., Zhou, M., Hu, Z., & Varshney, R. K. (2025). Novel Strategies for Designing Climate-Smart Crops to Ensure Sustainable Agriculture and Future Food Security. In *Journal of Sustainable Agriculture and Environment* (Vol. 4, Number 2). John Wiley and Sons Inc. <https://doi.org/10.1002/sae2.70048>
- Rios-Carlos, M., Cervantes-García, D., Córdova-Dávalos, L. E., Bermúdez-Humarán, L. G., & Salinas, E. (2024). Unraveling the gut-skin axis in atopic dermatitis: exploiting insights for therapeutic strategies. In *Gut Microbes* (Vol. 16, Number 1). Taylor and Francis Ltd. <https://doi.org/10.1080/19490976.2024.2430420>
- Satheesha Nayak, B., Ann, C. Y., Azhar, A. Bin, Ling, E. C. S., Yen, W. H., & Ashwini Aithal, P. (2017). A study on scalp hair health and hair care practices among Malaysian medical students. *International Journal of Trichology*, 9(2), 58–62. https://doi.org/10.4103/ijt.ijt_76_16
- Shah, R. R., Larrondo, J., Dawson, T., & McMichael, A. (2024). Scalp microbiome: a guide to better understanding scalp diseases and treatments. *Archives of Dermatological Research*, 316(8). <https://doi.org/10.1007/s00403-024-03235-2>
- Shi, H., Wang, X., Li, X., & Feng, Y. (2025). Pathogenic Mechanisms and Mechanism-Directed Therapies for Androgenetic Alopecia: Current Understanding and Future Directions. In *Dermatologic Therapy* (Vol. 2025, Number 1). John Wiley and Sons Inc. <https://doi.org/10.1155/dth/9950475>
- Singh, G., Pathania, Y., Goswami, P., Tyagi, S., & Patel, T. (2025). Folliculitis Decalvans: An Uncommon Case Report with Review of Literature. *International Journal of Applied & Basic Medical Research*, 15(1), 63–65. https://doi.org/10.4103/ijabmr.ijabmr_414_24
- Sivamani, P., Rajendran, R. L., Gangadaran, P., & Ahn, B. C. (2024). An induced pluripotent stem cell-based approach for hair follicle development and regeneration. In *Regenerative Therapy* (Vol. 26, pp. 502–507). Japanese Society of Regenerative Medicine. <https://doi.org/10.1016/j.reth.2024.07.005>
- Sivori, F., Cavallo, I., Truglio, M., De Maio, F., Sanguinetti, M., Fabrizio, G., Licursi, V., Francalancia, M., Fraticelli, F., La Greca, I., Lucantoni, F., Camera, E., Mariano, M., Ascenzioni, F., Cristaudo, A., Pimpinelli, F., & Di Domenico, E. G. (2024). Staphylococcus aureus colonizing the skin microbiota of adults with severe atopic dermatitis exhibits genomic diversity and convergence in biofilm traits. *Biofilm*, 8. <https://doi.org/10.1016/j.bioflm.2024.100222>
- Skowron, K., Bauza-kaszewska, J., Kraszewska, Z., Wiktorczyk-kapischke, N., Grudlewska-buda, K., Kwiecińska-piróg, J., Walecka-zacharska, E., Radtke, L., & Gospodarek-komkowska, E. (2021). Human skin microbiome: Impact of intrinsic and extrinsic factors on skin microbiota. In *Microorganisms* (Vol. 9, Number 3, pp. 1–20). MDPI AG. <https://doi.org/10.3390/microorganisms9030543>
- Smith, A., Dumbrava, R., Ghorri, N. U. H., Foster, R., Campbell, J., Duthie, A., Hoyne, G., Rademaker, M., & Bowen, A. C. (2025). An Overview of the Skin Microbiome, the Potential for Pathogen Shift, and Dysbiosis in Common Skin Pathologies. In *Microorganisms* (Vol. 13, Number 1). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/microorganisms13010054>

- Starace, M., Yamagata, J. P., Cortez de Almeida, R. F., Frattini, S., Bruni, F., Alessandrini, A., Iorizzo, M., Melo, D. F., Neri, I., & Piraccini, B. M. (2023). A Practical Algorithm for the Management of Superficial Folliculitis of the Scalp: 10 Years of Clinical and Dermoscopy Experience. *Dermatology Practical and Conceptual*, 13(3). <https://doi.org/10.5826/dpc.1303a131>
- Sun, T., Niu, X., He, Q., Chen, F., & Qi, R. Q. (2023). Artificial Intelligence in microbiomes analysis: A review of applications in dermatology. In *Frontiers in Microbiology* (Vol. 14). Frontiers Media S.A. <https://doi.org/10.3389/fmicb.2023.1112010>
- Suzuki, K., Inoue, M., Cho, O., Mizutani, R., Shimizu, Y., Nagahama, T., & Sugita, T. (2021). Scalp microbiome and sebum composition in japanese male individuals with and without androgenetic alopecia. *Microorganisms*, 9(10). <https://doi.org/10.3390/microorganisms9102132>
- Tao, R., Li, R., & Wang, R. (2021). Skin microbiome alterations in seborrheic dermatitis and dandruff: A systematic review. In *Experimental Dermatology* (Vol. 30, Number 10, pp. 1546–1553). John Wiley and Sons Inc. <https://doi.org/10.1111/exd.14450>
- Wang, X., Wang, X., Liu, J., Cai, T., Guo, L., Wang, S., Wang, J., Cao, Y., Ge, J., Jiang, Y., Tredget, E. E., Cao, M., & Wu, Y. (2016). Hair Follicle and Sebaceous Gland De Novo Regeneration With Cultured Epidermal Stem Cells and Skin-Derived Precursors. *Stem Cells Translational Medicine*, 5(12), 1695–1706. <https://doi.org/10.5966/scrm.2015-0397>
- Wang, Y., Li, J., Zou, Y., Wu, J., Gu, S., Hu, H., Cai, R., & Wang, M. (2023). Effects of a Postbiotic *Saccharomyces* and *Lactobacillus* Ferment Complex on the Scalp Microbiome of Chinese Women with Sensitive Scalp Syndrome. *Clinical, Cosmetic and Investigational Dermatology*, 16, 2623–2635. <https://doi.org/10.2147/CCID.S415787>
- Wojciechowska, K., & Dos Santos Szewczyk, K. (2025). The Skin Microbiome and Bioactive Compounds: Mechanisms of Modulation, Dysbiosis, and Dermatological Implications. In *Molecules* (Vol. 30, Number 22). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/molecules30224363>
- Woo, J., Suh, W., & Sung, J. H. (2022). Hair Growth Regulation by Fibroblast Growth Factor 12 (FGF12). *International Journal of Molecular Sciences*, 23(16). <https://doi.org/10.3390/ijms23169467>
- Xing, Y. Z., Guo, H. Y., Xiang, F., & Li, Y. H. (2024). Recent progress in hair follicle stem cell markers and their regulatory roles. *World Journal of Stem Cells*, 16(2), 126–136. <https://doi.org/10.4252/wjsc.v16.i2.126>
- Xu, C., Li, W., Lin, L., Zhang, D., Lei, J., Pan, D., Liang, S., Chen, Y., Wan, Y., & He, J. (2025). High-throughput sequencing to analyze changes in the human scalp microbiome during the use of a shampoo. *BMC Microbiology*, 25(1). <https://doi.org/10.1186/s12866-025-04260-5>
- Yin, C. S., Minh Nguyen, T. T., Yi, E. J., Zheng, S., Bellere, A. D., Zheng, Q., Jin, X., Kim, M., Park, S., Oh, S., & Yi, T. H. (2024). Efficacy of probiotics in hair growth and dandruff control: A systematic review and meta-analysis. In *Heliyon* (Vol. 10, Number 9). Elsevier Ltd. <https://doi.org/10.1016/j.heliyon.2024.e29539>
- Yu, H., Li, J., Wang, Y., Zhang, T., Mehmood, T., & Habimana, O. (2025). Dysbiosis and genomic plasticity in the oily scalp microbiome: a multi-omics analysis of dandruff pathogenesis. *Frontiers in Microbiology*, 16. <https://doi.org/10.3389/fmicb.2025.1595030>
- Yuan, C., Liu, L., Zeng, D., Yuan, J., Guo, L., & Zhang, J. (2025). Exploring the influence of gut microbiota metabolites on vitiligo through the gut-skin axis. In *Frontiers in Microbiology* (Vol. 16). Frontiers Media SA. <https://doi.org/10.3389/fmicb.2025.1566267>
- Zhang, H., Luan, J., He, L., Pan, X., Zhang, H., Li, Y., & Li, H. (2025). Role of the gut-brain axis in neurological diseases: Molecular connections and therapeutic implications (Review). In *International Journal of Molecular Medicine* (Vol. 56, Number 5, p. 192). Spandidos Publications. <https://doi.org/10.3892/ijmm.2025.5633>
- Zhao, Y., Chenchen, Y. U., Zhang, J., Qinghua, Y. A. O., Xiao, Z. H. U., & Zhou, X. (2025a). The gut-skin axis: Emerging insights in understanding and treating skin diseases through gut microbiome modulation (Review). In *International Journal of Molecular Medicine* (Vol. 56, Number 6). Spandidos Publications. <https://doi.org/10.3892/ijmm.2025.5651>
- Zhao, Y., Chenchen, Y. U., Zhang, J., Qinghua, Y. A. O., Xiao, Z. H. U., & Zhou, X. (2025b). The gut-skin axis: Emerging insights in understanding and treating skin diseases through gut microbiome modulation (Review). In *International Journal of Molecular Medicine* (Vol. 56, Number 6). Spandidos Publications. <https://doi.org/10.3892/ijmm.2025.5651>
- Zouboulis, C. C., Oeff, M. K., Hiroi, N., Makrantonaki, E., & Bornstein, S. R. (2021). Involvement of Pattern Recognition Receptors in the Direct Influence of Bacterial Components and Standard Antiacne Compounds on Human Sebaceous Gland Cells. *Skin Pharmacology and Physiology*, 34(1), 19–29. <https://doi.org/10.1159/000513259>