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The Science of a Beautiful Scalp

The Chemical and Mechanical Effects of Glycolic Acid on the Scalp

CROSSCHEM

Introduction

Glycolic acid has a proven track record in the personal care industry as a versatile and effective tool for anti-aging and cosmetic rejuvenation. Utilized in a variety of dermal applications and increasingly known for its use in hair care, glycolic acid is an α-hydroxy acid renowned for its abilities to both effectively rejuvenate skin and strengthen hair. The smallest and simplest of the α-hydroxy acids, glycolic acid is a naturally-occurring molecule that has shown to be highly effective in penetrating the skin surface and chemically exfoliating and replenishing the skin.

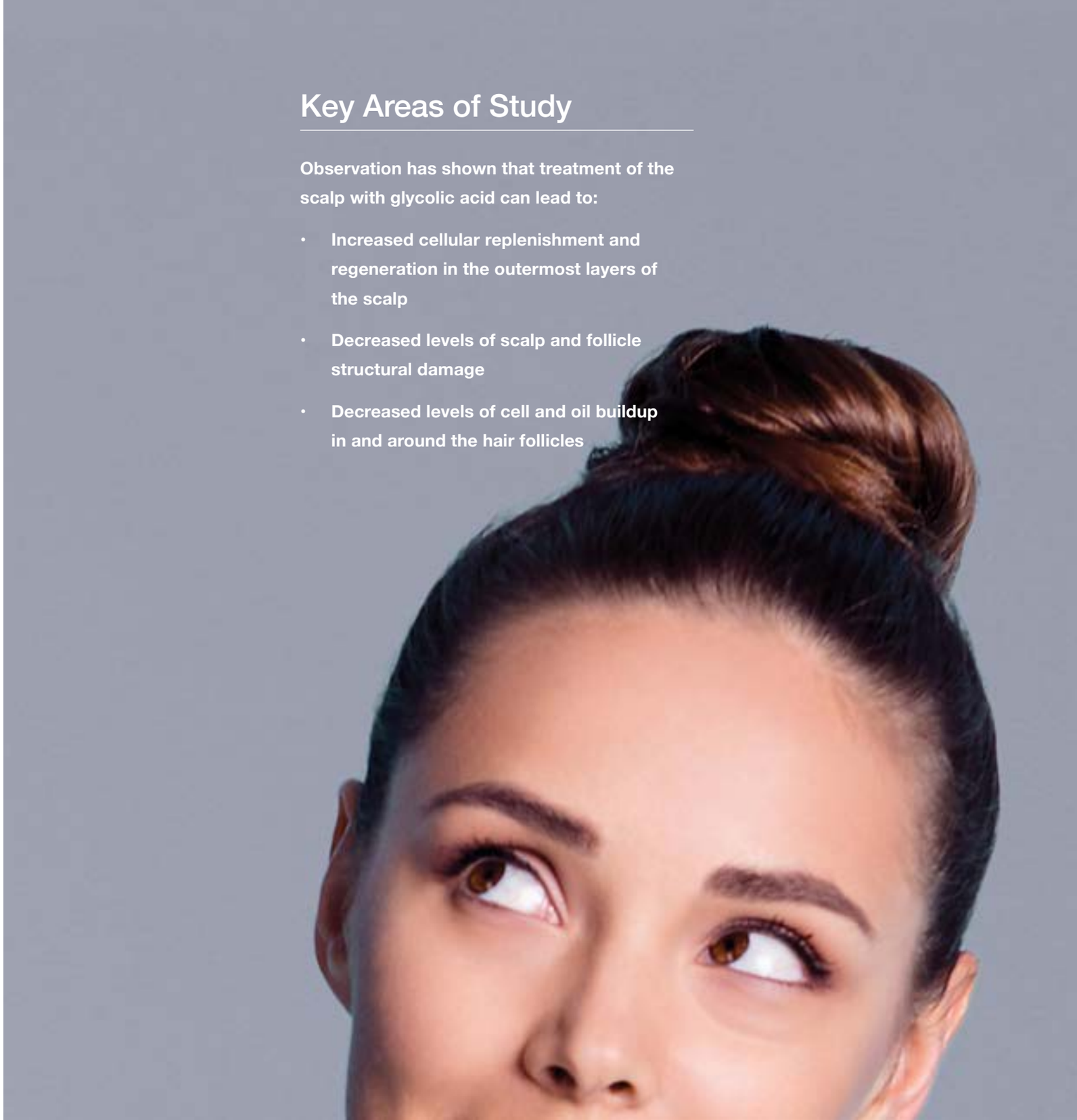
The scalp, while often overlooked in favor of the more widely-studied hair and skin surfaces, is an integral component of both personal appearance as well as physical health. Tajran and Gosman, in *Anatomy, Head and Neck, Scalp* describe how "In addition to its physical defenses, the scalp is important aesthetically. Hair grows on the skin of the scalp to not only aid in heat conservation but to also play a role in an individual's appearance" [1]. As the point of connection between the skin and the hair, the scalp serves as a lynch-pin in holistic health for the exterior of the body.

While the effectiveness of glycolic acid as an exfoliator for exposed skin surfaces has been previously demonstrated, less attention has thus far been given to the benefits from interactions between glycolic acid and the human scalp. Observation has shown that treatment of the scalp with glycolic acid can lead to increased cellular replenishment and regeneration in the outermost layers of the scalp, decreased levels of scalp and follicle structural damage, and decreased levels of cell and oil buildup in and around the hair follicles.

Key Areas of Study

Observation has shown that treatment of the scalp with glycolic acid can lead to:

- **Increased cellular replenishment and regeneration in the outermost layers of the scalp**
- **Decreased levels of scalp and follicle structural damage**
- **Decreased levels of cell and oil buildup in and around the hair follicles**



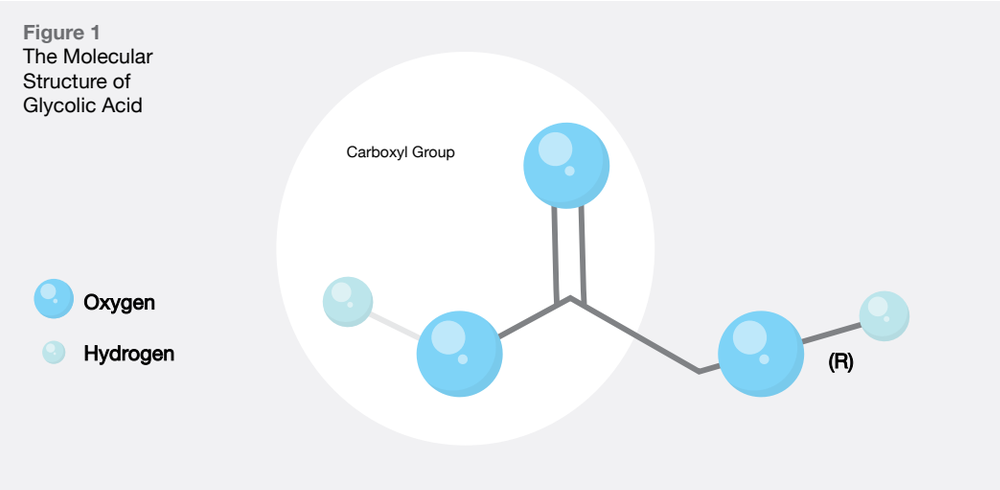


Figure 1
The Molecular Structure of Glycolic Acid

Increased Cellular Replenishment and Regeneration

Chemical and Molecular Properties of Carboxylic Acids

Carboxylic acids are acids containing carboxyl functional groups, and include glycolic acid, an α-hydroxy acid. The molecular structure of carboxylic acids makes them polar molecules, containing hydrogen-bond acceptors (the carbonyl functional group) and hydrogen-bond donors (the hydroxyl functional group) **(Figure 1)**. These structures allow carboxylic acids, including the α-hydroxy acids to facilitate hydrogen bonding, and make carboxylic acids effective reactants in dermal and epidermal applications. In Alpha-hydroxyacids and carboxylic acids, Yu et al. states "[α-hydroxy acids] are organic hydroxyacids, a group of natural and physiological substances which can modulate skin keratinization and increase biosynthesis of dermal components" [11].

The Structure of the Scalp

For humans, the scalp is a key component of physical appearance as well as a protective system for the critical areas of the human skull. Aesthetically, it serves as an area where hair can grow and physically, as a barrier that defends the body from foreign irritation" [1]. The scalp is structured into five primary layers, the skin, connective tissue, epicranial aponeurosis, loose areolar tissue, and pericranium, each serving a specific function that together allow the scalp to be durable and efficient in repelling pathogens and protecting the cranium (skull) [2].

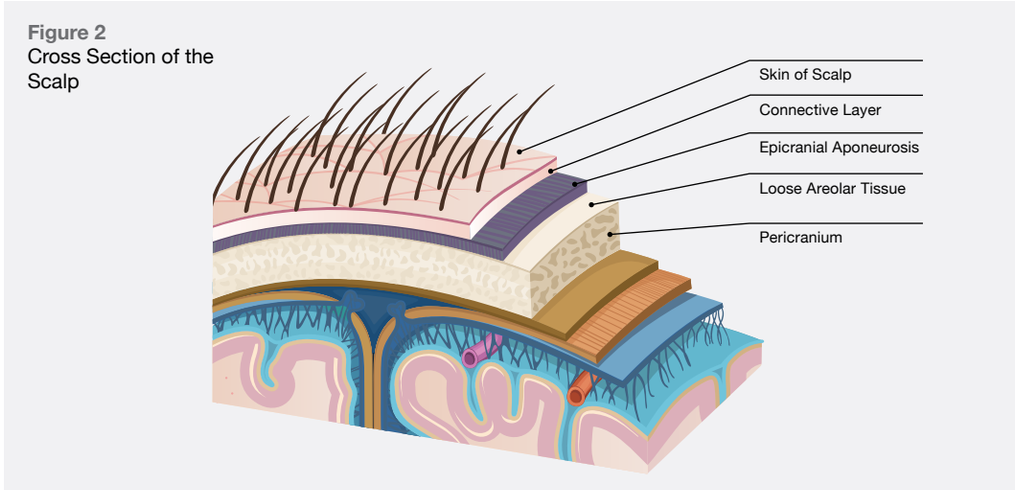


Figure 2
Cross Section of the Scalp

As seen in **Figure 2**, the outermost layer of the scalp is the skin. Like other external surfaces of the human body, the skin of the scalp is multi-layered to provide both flexibility and strength. In common with skin on other parts of the body, the skin of the scalp comprises the epidermal and dermal layers specialized to produce large quantities of hair and provide additional protection for the cranium [3]. In *The Surgical Anatomy of the Scalp,* Ellis and Mahadevan describe how the skin of the scalp "is thick, variably hair-bearing and is the area of skin most richly endowed with sebaceous glands, hence its greasy feel. In consequence of this concentration of sebaceous glands, the scalp is the commonest site for sebaceous cysts" [5]. The skin of the scalp utilizes collagen-containing matrix structures called ***corneodesmosomes*** to protect and support cells and hair follicles. The skin layer of the scalp is the primary portion of the scalp that interacts with external chemical, mechanical, and biological factors.

The layer beneath the skin is the ***connective layer*** which "forms the bridge between the skin and the epicranial aponeurosis by connecting the two together" [6]. The blood vessels in this layer are key in supplying necessary nutrients to the scalp. Below the connective layer, the ***epicranial aponeurosis*** is "a thin but tough layer of fibrous tendinous tissue" which gives the scalp limited mobility and malleability and helps the scalp effectively cover much of the skull [6]. Connected to this layer from below is the ***loose areolar tissue***, a varied collection of connective elements that "allows the other layers of the scalp to slide over the pericranium" [6]. Finally, the most internal layer of the scalp is the ***pericranium***, which protects the skull, provides nutrition to the bone and facilitates the ability of the scalp to repair itself. Together, these five primary layers allow the scalp to both protect the skull, grow hair necessary for thermoregulation, and serve as versatile and repairable shield against potentially harmful external pathogens.

The Epidermal Layer of the Scalp

As the primary site of scalp hair follicles and the outermost layer of the scalp, the skin is one of the key aspects of scalp health. Like other epidermal surfaces, the epidermis of the scalp is a stratified skin layer capped by a layer known as the ***stratum corneum***. Comprising layers of keratinized squamous cells, the stratum corneum layer is optimized for its shielding role through a waterproof construction that minimizes evaporation from underlying tissues and absorbs physical or chemical stresses from environmental factors [4]. In *The Stratum Corneum: Structure and Function in Health and Disease,* the author details how "in its most widely appreciated context, the critical skin barrier function refers to the epidermal barrier to water loss" [7]. Additional research by O'goshi et al. in *Functional Analysis of the Stratum Corneum of Scalp Skin: Studies in Patients with Alopecia Areata and Androgenetic Alopecia* demonstrates that in terms of role and effectiveness, the stratum corneum of the scalp plays a functionally similar role to stratum corneum elsewhere on the body in terms of maintaining skin health and protecting underlying tissues. O'goshi et al. state that "the water barrier function of the [stratum corneum] of the scalp resembles that of the volar forearm" [8].

Like epidermal stratum corneum elsewhere on the body, the effectiveness and health of the stratum corneum of the scalp is correlated to the structural integrity of its cell layers **(Figure 3).** Composed of keratinized, or non-living cells in corneodesmosome matrices, the stratum corneum works to protect and shield the skin

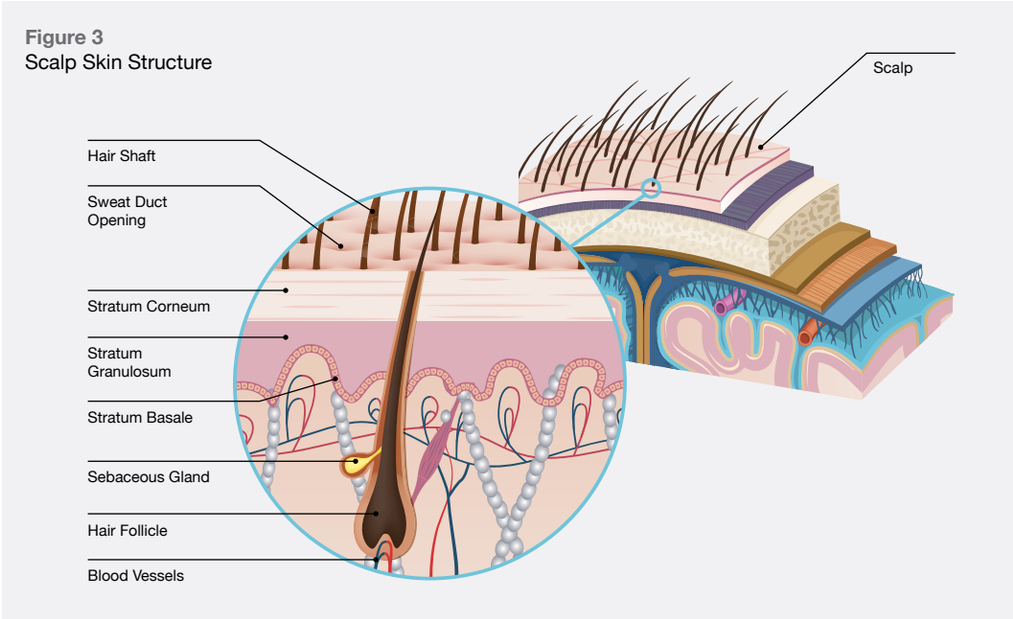


Figure 3
Scalp Skin Structure

against physical damage. Serving as the outermost layer of the skin, inevitably stratum corneum cells are exposed to environmental stresses and become damaged. The body thus sheds these outermost cells through peeling, also called ***desquamation***. In *Desquamation in the Stratum Corneum,* Torbjörn Egelrud writes, "To maintain a constant thickness of the stratum corneum the desquamation rate and the de novo production of [skin cells] is delicately balanced" [9]. In the scalp, the stratum corneum is often subjected to biological stresses from bacteria, chemical stresses from perms and many other types of hair treatments, and physical stresses from processes such as heating, straightening, curling, and exposure to ultraviolet rays from sunlight. The process by which the outer layers of the skin are replenished, however, are dependent on both localized conditions and the health of the individual. Skin damage or biological imbalances can facilitate disturbances, and "results in the accumulation on the skin surface of only partially detached cells with or without a concomitant thickening of the stratum corneum" [9].

Prior research has shown that as cells shed from the stratum corneum, new stratum corneum skin cells (corneocytes) move towards the skin surface and differentiate to replace older corneocytes. The time for corneocytes moving through the epidermal layer of normal skin to reach the stratum has been shown to be roughly fourteen days [10]. This timetable was specified for scalp cells in *Functional Analysis of the Stratum Corneum of Scalp Skin: Studies in Patients with Alopecia Areata and Androgenetic Alopecia,* where the authors calculated that "the epidermal proliferative

activity of the scalp seems to be far lower than that of the face resulting in a functionally better SC than that of the facial skin… from such data, we think that the turnover time for the scalp [stratum corneum] is around 10 days" [8].

Molecular Interactions between the Scalp and Glycolic Acid

In [8], O'goshi et al. link the side effects of hair and cosmetic treatments to scalp damage. Glycolic acid, the simplest of the α-hydroxy acids, has a small size and predictable chemical properties that allow it to interact with the stratum corneum and cause desquamation of epidermal corneocytes. In [7], Harding details how the corneodesmosomes structures linking corneocytes in the stratum corneum are the primary cohesive force which must be degraded for large-scale desquamation [7]. To rejuvenate the health of the skin on the scalp, glycolic acid-induced desquamation of the scalp can help the scalp shed damaged corneocytes and replace them with newer, healthier scalp cells. In *Interaction Between Bovine Collagen and Glycolic Acid Peeling: A Proposal of a New Protocol,* Sito and Sorrentino note that following topical application of glycolic acid, cohesion between corneocytes decreases via ionic bonding interference [12].

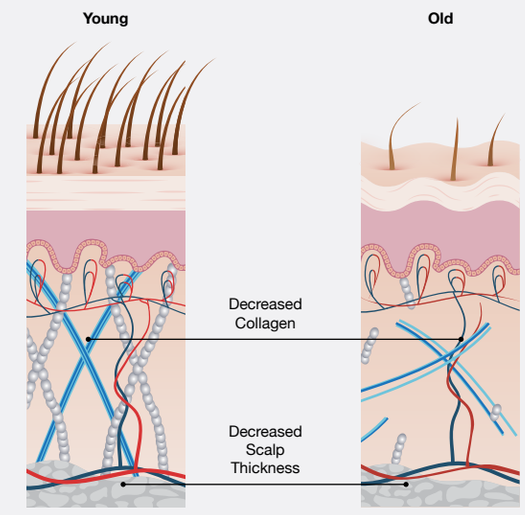
The polar molecular geometry and small size of glycolic acid allow it to enter the stratum corneum of the scalp and interact with matrices between corneocytes, disrupting adhesion. In *Retention of Corneodesmosomes and Increased Expression of Protease Inhibitors in Dandruff,* Singh et al. note that in a study of the scalp, "the retention of corneodesmosomes, in a pattern similar to dry skin is a characteristic feature of the perturbed desquamation" [13]. The insertion of glycolic acid to the stratum corneum of the scalp allows glycolic acid to bind within the corneodesmosomes matrices between corneocytes and spurs comprehensive replenishment of scalp cells via wide-scale desquamation. In *Cosmetic and dermatologic use of alpha hydroxy acids,* Babilas et al. note that "[α-hydroxy acids induce] desquamation… by interfering with intercellular ionic bonding… and thus inducing keratolysis" [14]. This helps rejuvenate scalp tissue by protecting healthy scalp cells and replacing damaged or aged cells.

Decreased Levels of Scalp and Follicle Damage

Scalp Tissue Health and Thickness

The maintenance of scalp health, as the area of the body from which the hair on the head originates, is a key topic in personal care. As discussed by the Advanced Hair Clinic, "once damaged, hair follicles are quite difficult to mend" while permanent damage to the skin of the scalp and the hair follicles in the area could result in hair that "can lose colour, volume, thickness and texture" [15]. The health and viability of the hair is related to the health of the hair follicles present in the scalp from which the hair grows. In many cases, accumulated damage to the scalp cells and follicles as part of everyday wear and tear and general ageing processes are implicated in the diminishing of scalp and follicle health **(Figure 4)**.

Figure 4
Dermal Fibroblast Ageing



As the skin of the scalp is subjected to environmental and age-related stressors, the health of the scalp stratum corneum can be compromised. Sito and Sorrentino note that as skin surfaces age, "the corneal strata is thicker and much more compact but the structure is irregular," while also calling attention to the fact that "the increase in compactness also determines a reduction in the water content; the epidermis is thinner overall and there is a reduction in the number of basal cells which can occasionally appear to be disorderly" [12]. In hair-bearing skin such as the scalp, the ageing processes that damage or degrade the structure of the local skin surfaces can also translationally lead to damaged hair follicles. As the scalp ages, the epidermal structures are subjected to a wide range of factors and forces that lead to structural and functional degradation, and in turn lead to hair follicle damage and decreased hair follicle production. Once hair follicles have been damaged, they shrink and produce finer and more fragile hair strands until the follicles die completely and hair loss becomes permanent. In scalp-specific terms, Trüeb et al. state that "according to the complex nature of the ageing process, the treatment for lifetime scalp and hair health has to be holistic to include the multitude of contributing factors" [16].

The links between ageing of the scalp and loss of hair follicle functionality were explored in

Figure 5
Loss of Hair Follicles with Scalp Thinning

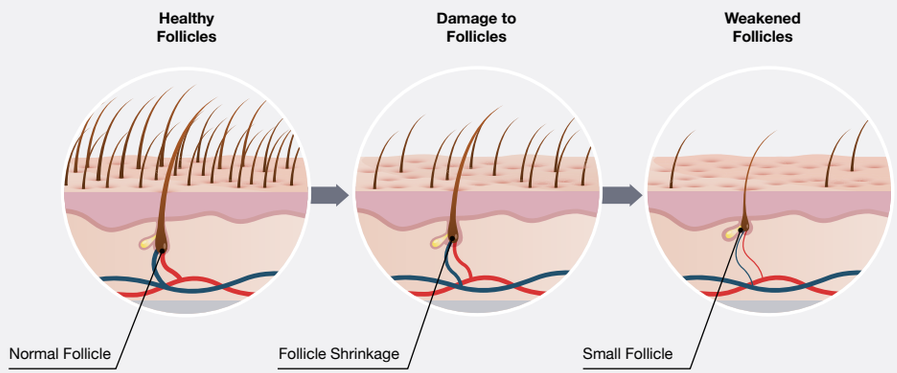
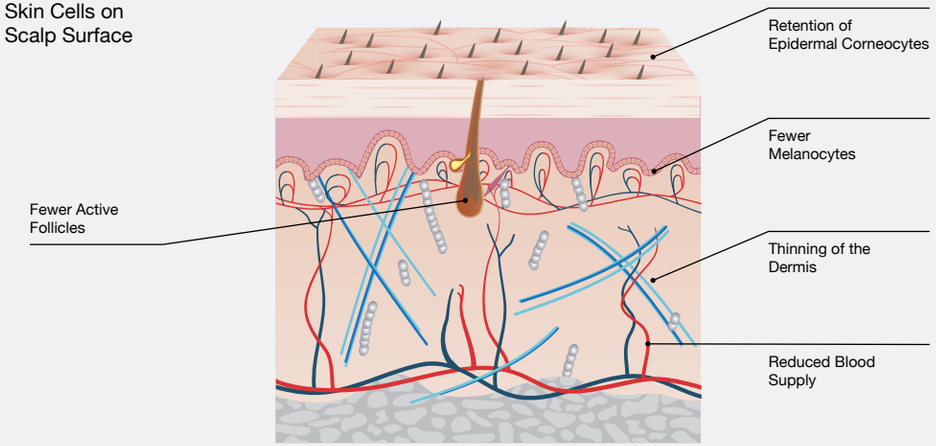


Figure 6
Retention of Skin Cells on Scalp Surface



Dysfunction of Hair Follicle Mesenchymal Progenitors Contributes to Age-Associated Hair Loss, where Shin et al. describe tissues ageing through "dermal thinning due to reduced extracellular matrix (ECM) density… accompanied by hair loss due to impairments in hair follicle (HF) epithelial progenitor cells" [21]. As the cellular support matrix in the scalp is degraded, destruction of the normal interface between corneocytes and structural molecules can lead to damaged or destroyed hair follicles **(Figure 5)**. In *A Comment of the Science of Hair Ageing,* Trüeb et al. further contend that "ultimately, aged hair follicle stem cells are poor at initiating proliferation and show diminished self-renewing capacity on extensive use" [16]. In *Maintaining a Healthy Scalp and Hair for Improved Hair Growth,* the author likewise states that "one of the easiest ways to help prevent most causes of pattern hair loss … is by maintaining a normal, healthy scalp and hair" [17].

Damage to Scalp Structural Integrity

In *Ageing and Photoageing of Keratinocytes and Melanocytes,* Yaar and Gilchrest describe how "decreased cell proliferation results in thinner and more slowly growing hair and nails and decreased secretory rates for holocrine glands" [18]. Research by Batisse in Influence of age on the wrinkling capacities of skin demonstrated that gradual alteration of collagen bundles appears as a consequence of ageing, which in turn leads to weakening of the mechanical structure epidermal layers [19]. In the scalp, the progressive ageing of skin structures lead to skin surfaces that are less orderly, with collagen fibers broken or incorrectly repaired **(Figure 6)**. In *Surgical Anatomy of the Scalp,* Seery links the durability of the scalp to the presence of structural collagen molecules in the tissue, preserving the structure of the scalp even when placed under mechanical stresses [23]. Skin deterioration thus corresponds to the fluctuating levels of collagen present within the skin, where ageing leads to "progressive atrophy of the collagen and elastic fiber bundles" [12]. Because of this, damaged cells can be replaced by misordered cells with less effective collagen matrices. In the scalp, this leads to a degraded ability to protect against physical, chemical and biological damage, an inability to maintain consistent levels of hair follicle production, and a lessening of hair production.

Strengthening of the Scalp with Glycolic Acid

Glycolic acid has become widely appreciated for its use in treating aged skin and stimulating rejuvenation and repair of chronic or photo ageing on skin surfaces. Glycolic acid bonds into corneodesmosome structures and exfoliates the outer stratum corneum layers, spurring the release of signals to stimulate the creation of new keratinocytes and collagen matrices. Babilas et al. noted in *Cosmetic and Dermatologic use of Alpha Hydroxy Acids* that treatment of aged skin with glycolic acid led to cosmetic and health improvements in the treated skin, stating that samples displayed "an enhancement of the granular layer, and an epidermal thickening" while also noting "some specimens displayed an increase in dermal collagen thickness" [14].

The overexpression of collagen subsequently restores damaged or lost intercellular matrix structures and guards against scalp thinning and the subsequent destruction of hair follicles. Topical application of α-hydroxy acids serves to initiate the synthesis of new corneocytes and collagen. As glycolic acid molecules bond with the corneodesmosome structure of the stratum corneum and cause the outer stratum corneum layers to peel, the skin stimulates the creation of new corneocytes as well as collagen to support it. This process allowed damaged regions of the stratum corneum to be replaced wholesale by newer and healthier tissues. Such replacement decreases the disruptions to skin texture caused by misordered cells and degraded collagen matrices and leads to increased thickness of the epidermis and greater support for hair follicles. Breakdown and subsequent replacement of the outer layers of the stratum corneum in the scalp accompanied by induced production of collagen and other supporting molecular structures leads to healthier hair follicles and better production of hair.

Decreased Levels of Cellular and Oil Buildup

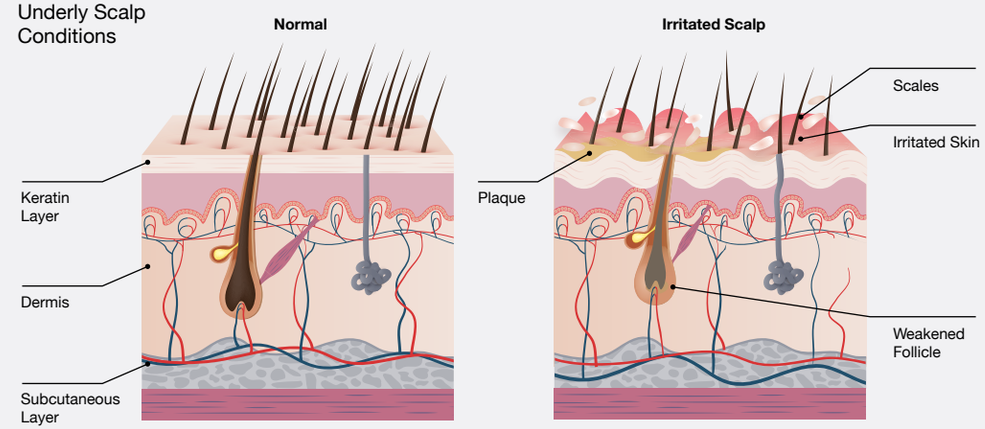
Characteristics of Dandruff and Dermatitis

Due to the presence of large concentrations of hair follicles, oil-producing sebaceous glands, and the potential for bacterial and/or fungal retention in the hair, the human scalp is a common site for irritation and infection. Conditions such and dandruff and seborrheic involve irregularities in normal scalp skin function and leads to flakiness and irritation of the scalp surface. In *Stratum Corneum Dysfunction in Dandruff,* Turner et al. write that "Dandruff is a common complaint; as much as half the global population will suffer from the condition at some time" [24]. Due to their widespread prevalence, these conditions are especially important given the relationships between scalp health and the quality of hair growth. Tosti and Schwartz, in *Role of Scalp Health in Achieving Optimal Hair Growth and Retention* contend that "the condition of the scalp can influence the quality of the hair which is produced" where distress placed upon the hair follicles by abnormal conditions in the scalp can result in stunted or perturbed production of hair [25].

Research has shown disruption of ***Epidermal barrier integrity*** to be a contributing factor in scalp conditions. Borda et al. state that "altered corneodesmosomal hydrolysis may disrupt lipid organization and disturb the desquamation process, leading to aberrant barrier function" in the stratum corneum [26]. The role of stratum corneum dysfunction in scalp conditions is further supported by research conducted by Kerr et al, which determined that "the presence of parakeratosis in [stratum corneum] samples from the dandruff condition suggests that hyperproliferation is a feature of the dandruff lesion… the key symptoms of dandruff are a consequence of the perturbation of permeability barrier function, which results in an autocatalytic cascade of inflammation that disrupts normal cell proliferation and differentiation" [27].

Stratum corneum damage as a trigger for scalp irritation through dandruff or dermatitis is further implicated in studies conducted [13], where the authors discuss how "Our findings indicate that the persistence of non-peripheral corneodesmosomes is a characteristic feature of the perturbed desquamation seen in dandruff" [13]. Previous analyses of skin conditions involving the accumulation of skin cells have demonstrated that an increased production of sebum, or skin oils, leads to over-retention of skin cells surrounding hair follicles. This in turn leads to dead skin cells clogging follicles and forming blockages [28]. Amongst the hair follicles of the scalp, heightened excretions from sebaceous glands can give rise to abnormal desquamation of scalp cells, leading to folliculitis, in which blocked pores become inflamed and infected and the skin becomes scaled, flaky, and dry **(Figure 7)**. Turner et al note that "the impaired barrier associated with the dandruff scalp exhibits an underlying propensity for hyperproliferation, altered corneocyte maturation processes and a subclinical inflammatory state" [24].

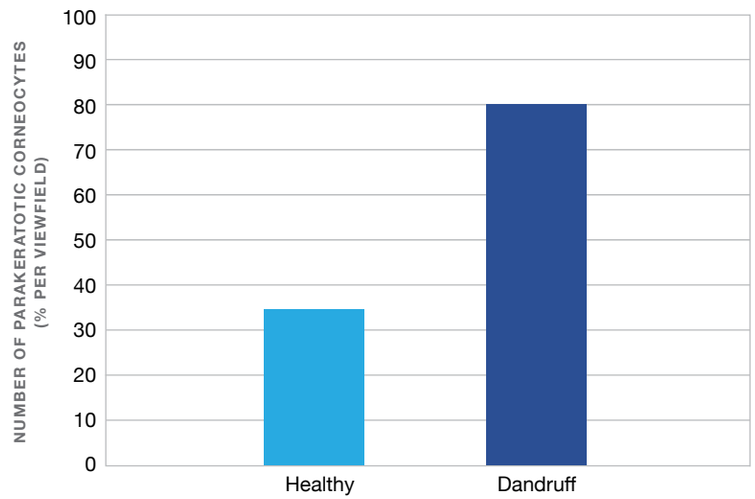
Figure 7
Mechanisms That Underly Scalp Conditions



Biology of Dandruff and Dermatitis

Singh et al. noted in *Retention of Corneodesmosomes and Increased Expression of Protease Inhibitors in Dandruff* that corneodesmosome matrices are the main connective structures in the stratum corneum. In the study, the authors identified "the persistence of non-peripheral corneodesmosomes

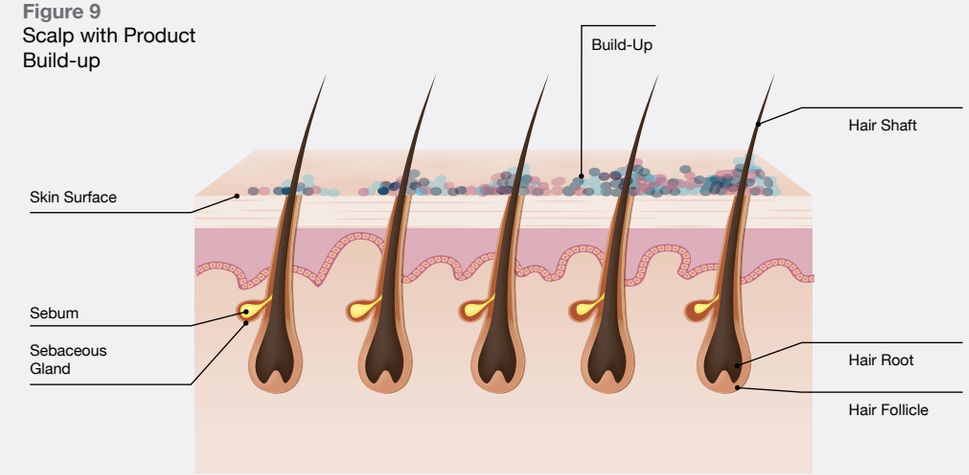
Figure 8
Corneocyte Retention in Healthy and Irritated Scalps



is a characteristic feature of the perturbed desquamation seen in dandruff providing a rationale for the characteristic clumping and flaking of [stratum corneum] observed" [13] **(Figure 8).** This study indicates that the structural matrices that fasten the outer stratum corneum in place are central in the irregular patterns of desquamation seen in scalp conditions such as dandruff and dermatitis. In *Seborrheic Dermatitis and Dandruff: A Comprehensive Review,* the authors discuss how "Normally, sebum may influence intercellular lipid organization to aid desquamation. In SD and dandruff, however, altered hydrolysis of the corneodesmosome may disrupt lipid organization and disturb the desquamation process, leading to aberrant barrier function" [26].

The overall efficacy of the stratum corneum requires that shedding (desquamation) and corneocyte production are complementary processes that maintain an equilibrium in the conditions of the stratum corneum. Conversely, in scalps suffering from conditions such as seborrheic dermatitis or dandruff, these processes are pushed into disequilibrium by shifts in sebum production and desquamation rates. Egelrud further states that "Disturbances in this process results in the accumulation on the skin surface of only partially detached cells with or without a concomitant thickening of the stratum corneum. The severity of the disturbance may vary from modest to very pronounced" [9]. Thus, while the buildup of corneocytes on the surface of the scalp contributes to the manifestation of dandruff and seborrheic dermatitis, it in turn offers a means by which the corneocyte retention can be countered.

Figure 9
Scalp with Product Build-up



Treating Scalp Conditions with Glycolic Acid

Kerr et al noted in *Epidermal Changes Associated with Symptomatic Resolution of Dandruff: Biomarkers of Scalp Health* that in subjects displaying dandruff or seborrheic dermatitis "the presence of hyperproliferation, altered differentiation and inflammation" contribute to "the development of the key symptoms of the condition (flakes and itch) by disrupting differentiation and orderly desquamation" [27]. Babilas et al. noted that treatment of a skin surface with an α-hydroxy acid loosens skin cells by ionically bonding with in the intercellular matrices, reducing corneocyte cohesion and spurring desquamation [14].

Glycolic acid has been shown to effectively react with corneodesmosome structures, freeing corneocyte deposits, facilitating removal of impacted skin cells, and spurring their replacement with newer, healthier corneocytes. Research by Cotellessa et al. in Glycolic Acid and its Use in Dermatology determined that "lower concentrations of glycolic acid cause a reduction of cohesion of follicular corneocytes" [27, 29]. Taken together, these principles illustrate that scalp conditions such as dandruff and seborrheic dermatitis can be treated via the application of glycolic acid formulations. By acting on the outer layers of the scalp and assisting in the elimination of the skin and sebum deposits that lead to scalp irritation and inflammation, glycolic acid help restore scalp health by decreasing the levels of skin cell and oil buildup around the hair follicles of the scalp **(Figure 9)**.

Conclusion

In this study, a comprehensive analysis of available research has elucidated the effects of glycolic acid on the human scalp. Glycolic acid is a naturally-occuring α-hydroxy acid appreciated in personal care for its abilities to both effectively rejuvenate skin and strengthen hair. In general, however, less attention has been paid to the ways in which glycolic acid interacts with and replenishes the scalp.

This study has shown that interactions on a molecular level between the human scalp and glycolic acid rely on the foundational principles of glycolic acid's effectiveness in exfoliating and rejuvenating skin. The specialized skin structure and prevalent hair follicles of the scalp are especially sensitive to changes in the equilibrium of skin cell production and desquamation, and glycolic acid serves as an effective tool in modulating a balance in these processes. Glycolic acid's small size, and stability allow it to ionically-bond with the scalp, shed damaged corneocytes and replace them with newer, healthier scalp cell layers. When exposed to damage from hair treatments, environmental factors, or ageing, the cells of the scalp can become disrupted or damaged. Glycolic acid's proven record as a skin therapy within personal care, alongside a thorough understanding of the epidermal structure of the scalp demonstrate its utility as a scalp therapeutic. The small size of the glycolic acid molecule when compared to other carboxylic acids allows effective penetration of the scalp, leading to total skin exfoliation and cleansing of hair follicles.

It can be seen that glycolic acid's potency in the support and rejuvenation of the human scalp is a result of its molecular structure and bonding capabilities. Improvements in the health of the scalp from increased cellular replenishment, decreased structural degradation and follicle damage, and decreased levels of cellular buildup around hair follicles can all be obtained through the use of glycolic acid treatments. The research evaluated in this study demonstrates that chemical effects from the addition of glycolic acid to scalp treatments can provide comprehensive benefits in the protection and support of the scalp tissue and cells.

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