GlyAcid®
glycolic acid

formaldehyde free

The Science of Beautiful Hair

The chemical and mechanical effects of glycolic acid on human hair keratin

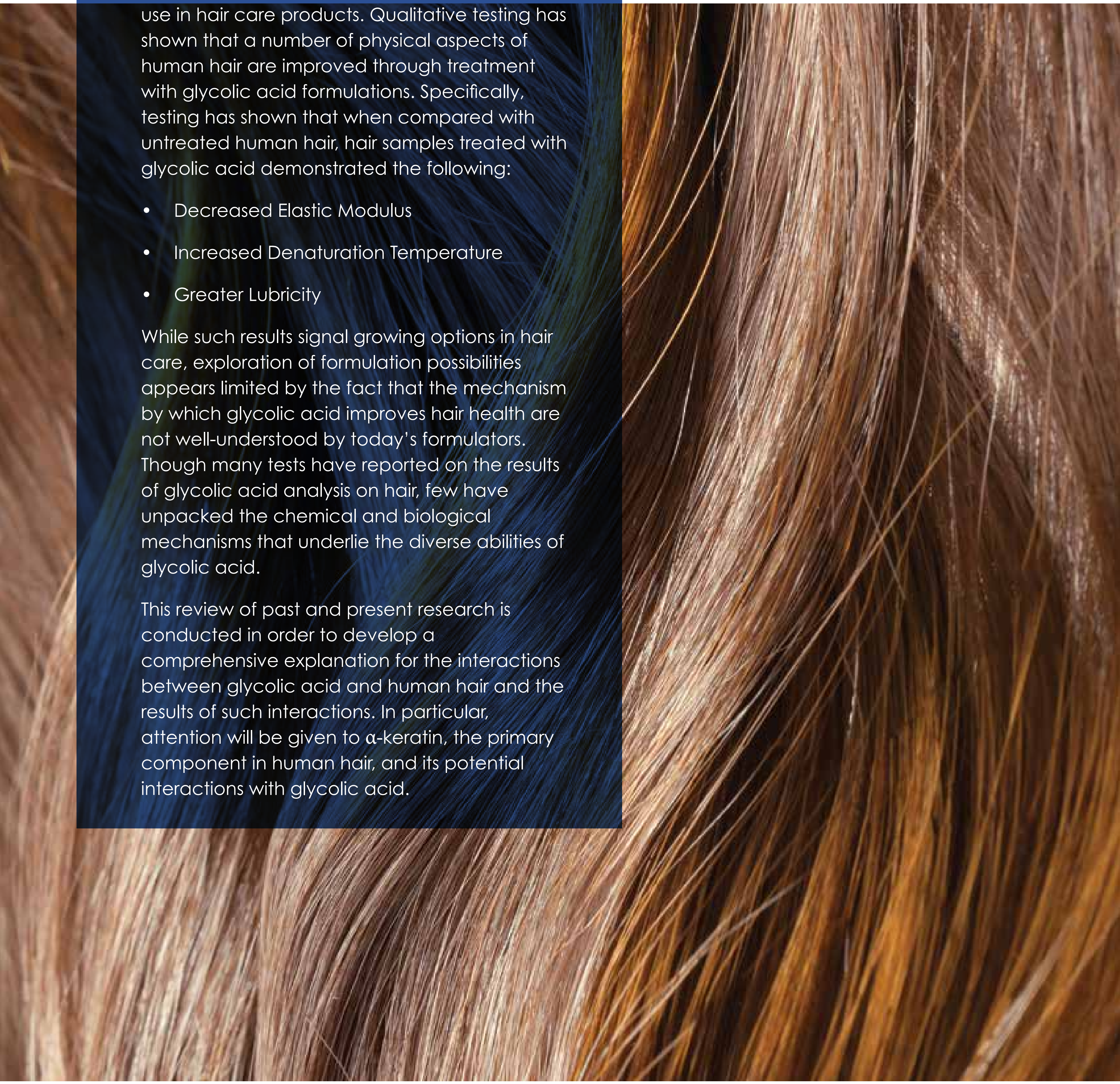
CROSSCHEM
PURE CHEMISTRY

Glycolic acid continues to proliferate globally in skin care products as a proven anti-aging active ingredient. In recent years, glycolic acid has also begun to attract attention for its potential use in hair care products. Qualitative testing has shown that a number of physical aspects of human hair are improved through treatment with glycolic acid formulations. Specifically, testing has shown that when compared with untreated human hair, hair samples treated with glycolic acid demonstrated the following:

- Decreased Elastic Modulus
- Increased Denaturation Temperature
- Greater Lubricity

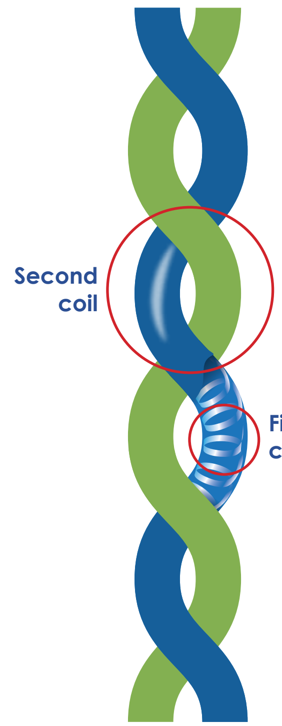
While such results signal growing options in hair care, exploration of formulation possibilities appears limited by the fact that the mechanism by which glycolic acid improves hair health are not well-understood by today's formulators. Though many tests have reported on the results of glycolic acid analysis on hair, few have unpacked the chemical and biological mechanisms that underlie the diverse abilities of glycolic acid.

This review of past and present research is conducted in order to develop a comprehensive explanation for the interactions between glycolic acid and human hair and the results of such interactions. In particular, attention will be given to α-keratin, the primary component in human hair, and its potential interactions with glycolic acid.



DECREASED
ELASTIC MODULUS

Alpha keratins (α-keratin) comprise most of the dry weight of hair. In α-keratins, polypeptide chains twist together to form a bonded coiled coil. These bonds impart stability to keratin structures[1]. The ability of these structures to unwind, even breaking internal H-bonds, allows α-helical structures to stretch. In healthy hair, shape can be restored[2]. When bonds in the hair shaft are damaged or broken, however, the flexibility of the hair is lost and it can become brittle, snarled, and frayed.



Both coils can begin to unwind during denaturation as bonds between the coils are broken and coils separate.

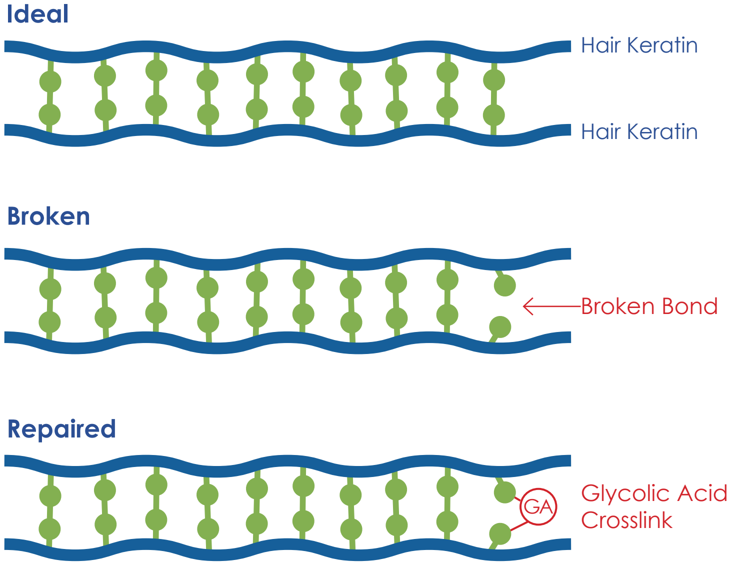
In a study by Evans et al, glycolic acid treatments are shown to significantly decrease the Young's modulus of hair. The report discusses how the change in characteristics is also reversible. This indicates that treatment with glycolic acid did not permanently alter the hair structure, instead inducing temporary softening[5]. As discussed in the study *Cosmetic and dermatologic use of alpha hydroxy acids,* the use of α-hydroxy acids as a plasticizer (softener) in cosmetic applications is well documented. As opposed to water, glycolic acid is also non-volatile[3]. In a study by Song et al, it is shown that carboxylic acids like the α-hydroxy acids help link functional groups on keratin molecules[7]. The report discusses how the addition of carboxylic acids like glycolic acid can help rebuild crosslinks between neighboring keratin molecules and repair broken hydrogen bonds.

Glycolic acid is a small, highly permeable α-hydroxy acid containing a carboxyl group as well as a hydroxyl group, and is ideally suited to rebuild stability in damaged hair, whether the hair was damaged naturally or through cosmetic treatments such as perms. In his study, Evans describes how many cosmetic chemical hair treatments significantly alter the characteristics of hair[5]. The small molecular and chemical architecture of glycolic acid allow it to effectively repair broken keratin bonds by penetrating deep into hair strands and instigating subsequent crosslink repair. As summarized in *Glycolic Acid No Longer Just For Skin – Changing the Internal Properties of Hair,* "treatment with glycolic acid significantly decreased the Young's modulus of hair," restoring natural hair elasticity, flexibility, and health"[5].

INCREASED
DENATURATION TEMPERATURE

Denaturation is when molecules such as proteins unwind and lose their intended shape. In human hair this can be caused by heat and predominantly affects the cortex region. T_D (denaturation temperature) in hair decreases significantly with increasing water content. This supports the theory that denaturation with temperature is kinetically controlled by chemical characteristics of the keratin matrix[4].

Glycolic acid interacts with broken keratin bonds and helps repair crosslinks between the alpha-keratin coil slices.



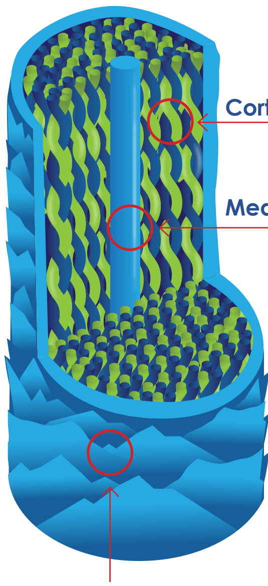
Glycolic acid, unlike water, is non-volatile. In *A Study on Keratin*, the authors note that "lateral links" are key in the stability of keratin structures[6]. This study also notes that when these bonds are broken, keratin molecules easily become denatured[6]. In essence, the mechanical effectiveness of keratin structures is linked to the strength of the crosslink bonds. It has been shown that in the case of natural hair, the presence of water as volatile plasticizers destabilize these bonds, leading to hair frailty[7]. Dynamic vapor sorption experiments have shown that glycolic acid treatments produced significant reductions in the water content compared to untreated hair[5]. By bonding in the keratin matrix, glycolic acid imparts greater stability to the structure while reducing the amount of water in the hair cortex.

It can be seen that the same chemical mechanisms underlie both increased T_D and decreased elastic modulus for hair keratin. The ability of glycolic acid to bond into keratin matrix networks strengthens keratin molecule interactions and reduces water content in the hair cortex[7]. The subsequent repair of hydrogen bonds by glycolic acid creates a more stably conformed keratin matrix and leads to an increased T_D for glycolic acid-treated hair.

INCREASED LUBRICITY

Elasticity and denaturation temperature are largely affected by properties in the cortex of a hair strand. The lubricity of hair, however, is derived from the outer "cuticle" of a strand of hair. The cuticle is composed of overlapping keratinized scale cells that surround the hair cortex, like shingle roofing. In practice, a loss of hair lubricity can occur when the cuticle scale cells become misaligned[10]. Jerreau and Clark also suggest how breaks in the cuticle allows water to seep into the hair strands, which can create 'kinks' as the strands swell non-uniformly[10]. As previously discussed, carboxylic acids effectively facilitate linkages between keratin molecules, imparting uniformity and stability to large keratinized structures[7]. In conjunction with the study by Evans, describing how hair with low water content looks and feels healthier, this illustrates that disorder in the hair cuticle can lead to greatly increased friction and snagging of hair, as the uniformly straight nature of hair strands is disrupted[5].

A cross-sectional view of the hair strand shows the internal structure, including the shaft cuticle and the coiled-coil cortex.



In *Here's the Chemistry Behind a Bad Hair Day...Or a Great One*, the authors note that the key to reordering the outer cuticle of the cell is to reseal it[10]. The article notes how keratin straightening treatments function by "brute-forcing" the hair strands. In such treatments, formaldehyde compounds are used to open the cuticle and heated keratin is injected into the cortex of hair strands. While treated hair may appear visually straighter, such procedures are superficial responses to cosmetic concerns. These procedures modify the hair cortex to increase hair straightness while the underlying causes of non-lubricity derive from the molecular characteristics of the hair cuticle.

In comparison to keratin straightening treatments, glycolic acid formulations allow hair lubricity to be improved more holistically, through repair on a molecular scale. Research has shown that flexible hydrogen bonding and cross-chain linkage in α-keratin structures give healthy hair its molecular order and characteristic versatility[6]. Experiments have also been conducted that show carboxylic acids to be effective in strengthening and maintaining polymeric chemical linkages in keratin[7]. The carboxyl functional group in this class of acids is known to form covalent linkages with the amine groups found on the amino acids that comprise keratin-like molecules. This suggest that glycolic acid increases human hair lubricity by rebinding the keratin scales of the hair shaft cuticle, so that intermolecular forces between neighboring keratin molecules in the α-keratin coils are regained[7]. Such repair increases lubricity by ordering the cuticle, and also prevents penetration of the hair strand by foreign molecules without relying on mechanical straightening to reduce hair entanglement.

CONCLUSION

The polymeric nature of human hair keratin formed into α-helical structures gives rise to molecular geometry well-suited to beneficial chemical interactions with glycolic acid. Studies on the characteristics of human hair keratin have demonstrated that linkages across and between proximally-located keratin strands within α-keratin imparts stability and flexibility to healthy human hair. This nature of keratin also contributes to brittleness, dullness, and general hair unhealthiness when cross linkages between hair strand keratins become broken and the molecules within the hair strand become separated and disordered.

Glycolic acid's effectiveness in repairing such breakages is shown to derive in part from glycolic acid's status as a carboxylic acid and in part to its composition as the smallest and simplest member of the family of α-hydroxy acids. The molecular structure of glycolic acid includes both carboxyl and hydroxyl functional groups, which are well-suited to bond covalently with the carboxyl and amine groups found in all amino acids, the base-level building blocks of proteins including keratin. Furthermore, it is believed that glycolic acid's small size when compared with other α-hydroxy and carboxylic acids allows it to more effectively penetrate hair strands, leading to a more productive distribution of glycolic acid compounds throughout the entirety of treated hair.

Overall, it can be seen that the molecular nature of glycolic acid provides demonstrated effectiveness in the improvement of human hair health. Improvements in hair characteristics such as denaturation temperature, elastic modulus, and lubricity may be obtained through the use of glycolic acid to repair broken molecular linkages within hair strands as well as prevent penetration of hair by unwanted foreign molecules. The data analyzed in this review shows that both healthy and damaged hair can benefit from the addition of glycolic acid to hair care formulated products.

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