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Mechanism of hair straightening

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Synopsis

The practice and theory of permanent hair straightening are discussed. Hair straightening as a cosmetic process is the reverse of hair waving. It removes hair curliness and makes wavy hair straight. While it is generally accepted that permanent hair straightening can be achieved only at very high pH with strong alkali, we have observed that it can also be achieved at neutral pH with lithium salt, or even at acidic pH with resorcinol. Also, while some of these treatments do result in considerable loss of cystine, others leave the cystine entirely intact. Lanthionine is produced in some cases, but is absent in others. It appears that the prime requirement for an effective hair straightening treatment is to be able to induce supercontraction of the hair fiber.

Based on these observations, a model is proposed to explain permanent hair straightening in terms of certain molecular events such as chain folding and alpha-beta transformation of the polypeptide in the hair keratin.

INTRODUCTION

Several processes are applicable to hair straightening, which has become one of the more common hair styling practices. There are the hot comb and press iron, which were popular years ago. There are the "Jeri-curl" products, and there are the chemical relaxers. They all are able to straighten hair to some extent, but not with the same degree of permanency. The hot comb process, for example, which relies on the actions of heat and moisture, can only achieve hair straightening that is temporary. The hair will revert to its original curly state even on exposure to high humidity. The Jeri-curl process, which is based on the "thioglycolate waving system," can produce hair straightening that is more resistant to humidity, but the hair will still revert on washing. The chemical relaxers, which are typically formulated with strong alkali at pH in excess of 13, are the only ones that are able to achieve permanent hair straightening that will survive washing. The general belief is that hair straightening is analogous to hair waving. When hair is treated with a chemical relaxer, hair cystine is cleaved, and a new crosslink, the lanthionine, is subsequently formed to help stabilize the hair in the straight configuration. The theory is reasonable in view of the fact that lanthionine is a major reaction product between alkali and cystine (1–3). Also, published data have shown that hair treated with chemical relaxers indeed contain, a substantial amount of lanthionine. However, we have observed several aspects of hair straightening that are unique in themselves and have led us to believe that permanent hair straightening is governed by a different molecular process.

EXPERIMENTAL

HAIR SAMPLES

Two types of hair samples were used in the experiments. Curly hair samples, obtained from Afro-Americans, were used to assess the efficacy of hair straightening. Typically, these hair samples consisted of coils of about 0.5 cm in diameter. To study the fiber swelling and supercontraction characteristics, Caucasian dark brown hair was used. All hair samples were cleaned with a solution of 12.5% sodium lauryl sulfate prior to treatments.

EVALUATION OF HAIR STRAIGHTENING EFFICACY

Temporary hair straightening is typically characterized by a ready reversion of the hair fiber to its original curliness after even one washing. A criterion that we used in this study to determine the permanency of hair straightening was how well the hair fiber remained in a straight configuration after the fiber was immersed in water (at room temperature) for five minutes and dried. The degree of hair straightness was determined visually: the hair fiber was considered straight when there was no evidence of curliness.

EVALUATION OF HAIR SWELLING AND HAIR SUPERCONTRACTION

To determine the degree of hair swelling, the diameter of a wet hair fiber was measured prior to treatment using a stereoscopic microscope equipped with an eyepiece that has a micrometer scale. The diameter of the same hair fiber was again measured after exposure to a treatment reagent. To determine the extent of fiber supercontraction, the length of straight Caucasian hair fiber was immersed in water and measured in a microcapillary before and after the treatment.

ANALYSIS OF CYSTINE AND LANTHIONINE CONTENT

Hair samples were first hydrolyzed by heating with 6 N HCl in a sealed tube for 24 hours at 110°C. After removal of the acid in a rotary evaporator at 30°C and dilution with 0.2 N sodium citrate buffer (pH 2.2), the amino acid content was determined with a Beckman 120-C amino acid analyzer.

RESULTS AND DISCUSSION

HAIR STRAIGHTENING WITH THIOGLYCOLATE/HYDROGEN PEROXIDE SYSTEM

One of the unusual aspects of hair straightening is the fact that conventional hair waving products are not particularly effective in achieving permanent hair straightening. When a straight hair fiber is set in a curly configuration (wound on a rod, for example) and treated with a commercial thioglycolate waving lotion for 30–40 minutes, followed by a neutralization step, the hair fiber will acquire a curly configuration that will survive subsequent washing. On the other hand, if a curly Afro hair fiber is set in a straight configuration (the fiber is held straight under a small strain, for example), and treated with a similar thioglycolate waving lotion and neutralization step, the hair fiber will acquire a temporary straight configuration. However, the hair fiber will revert to most of its original curliness on even one subsequent washing. The failure of this reduction/re-oxidation scheme to impart a more permanent straightness to the hair fiber suggests that a molecular model comparable to hair waving may not be entirely applicable.

THE PHENOMENON OF SPONTANEOUS HAIR UNCOILING

Another unique aspect of hair straightening is the spontaneous uncoiling of the hair fiber. Placed in a solution of appropriate reagent, a curly hair will uncoil itself without the help of an external force. This phenomenon can be demonstrated by the following experiment: A curly hair fiber is immersed in a 1 N sodium hydroxide solution. The curvature of the hair is observed and can be seen to increase slowly, and in about 10 to 15 minutes, the hair fiber becomes practically straight. In other words, unlike hair waving, hair straightening can be achieved without the application of an external force to strain the hair fiber.

The question arises as to what causes the curly hair fiber to uncoil and allow hair straightening to proceed. We thought of two possibilities: One explanation could be the swelling action of the reagent, since sodium hydroxide is an excellent swelling agent for keratin fiber. In fact, it has been pointed out in the literature (5,6) that, based entirely on geometrical consideration, any radial swelling of a curved segment of a fiber should result in an increase in the radius of curvature of the fiber. Another explanation could be the result of fiber supercontraction (7). In fact, under closer examination, as shown in Figure 1, it can be seen that in a 1 N sodium hydroxide solution, the uncoiling of the hair fiber is accompanied by some changes in fiber geometry.

HAIR SWELLING AND HAIR SUPERCONTRACTION

To assess the relative importance of these two factors to permanent hair straightening, we proceeded to examine the swelling and supercontraction behavior of hair fibers in a variety of reagents and to establish how they would impact on hair straightening. In this set of experiments, curly Afro hair fibers were treated with various reagents, some of which are known to be good keratin swelling agents, while others are also known to cause supercontraction in keratin fibers. These reagents included sodium hydroxide, resorcinol, lithium chloride, urea, dithiothreitol (DTT), thioglycolic acid (TGA), tris (hydroxymethyl)phosphine (THP), boiling water, and cuprammonium hydroxide. The degree of hair swelling and the amount of fiber supercontraction were measured and correlated with the corresponding degree of permanent hair straightening. Results are shown in Table I below.

It is interesting that while all the reagents in the study are effective hair swelling media, permanent hair straightening is achieved only by those that are also able to induce hair supercontraction. From the data shown in Table I, it is obvious that effective hair

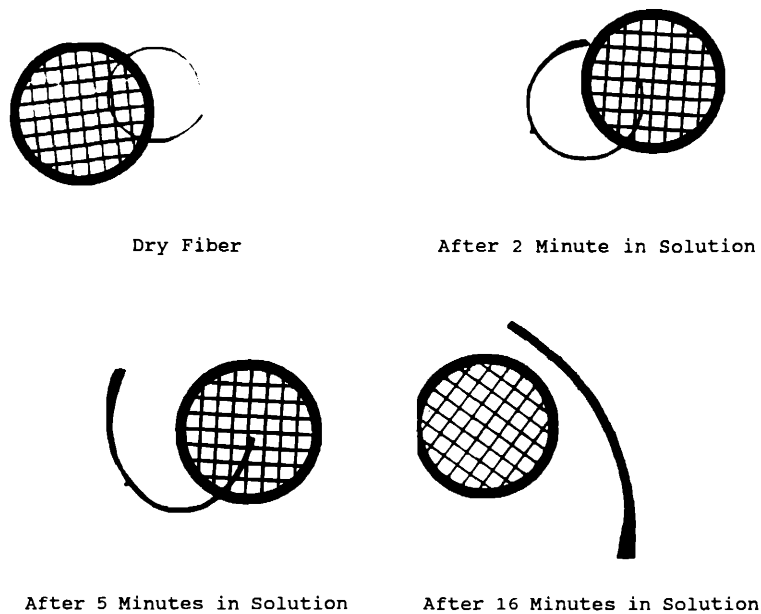

Figure 1. Changes in curvature and fiber diameter of curly hair fiber immersed in 1 N sodium hydroxide solution (grid circle is used as reference).

Table I
Relationship of Hair Swelling and Fiber Supercontraction to Permanent Hair Straightening

Reagents	pH	Degree of hair straightening	% Hair swelling	% Hair supercontraction
NaOH (1 N)	14.0	Complete/permanent	>40	5.7
NaOH (0.1 N)	13.0	Partial/temporary	40	0
DTT (0.8 M)	3.5	None	>50	0
THP (1 M)	8.5	Complete/permanent	>50	6
Urea (50%)	7.0	None	>30	0
TGA (1.2 M)	9.6	Partial/temporary	80 [11]	2.0
LiCl (40%)	7.0	Complete/permanent	60 [12]	11.5
Resorcinol (40%)	7.0	Complete/permanent	>50	10.0
Boiling water*		Complete/permanent	>15 [13]	6.0
Cuprammonium hydroxide	12.0	Complete/permanent	>50 [14]	9.4

* Under tension.

straightening can only be achieved when the hair fiber has supercontracted 5% or more of its own length. Reagents such as urea, dithiothreitol, and thioglycolic acid are all excellent swelling agents for the hair fiber, and yet none of these reagents would be able to impart any degree of permanent hair straightening. In fact, sodium hydroxide at a concentration as high as 0.1 N is not a particularly effective hair straightener, since at this concentration, sodium hydroxide is not producing a significant amount of fiber supercontraction. Boiling water, on the other hand, will produce effective hair straightening if the hair fiber is strained to about 20%, since under these conditions hair fiber is believed to undergo supercontraction (8). It thus appears that fiber swelling alone will not be sufficient without also the presence of fiber supercontraction. Indeed, hair fiber supercontraction is perhaps the dominant requirement.

The importance of fiber supercontraction is further demonstrated by the observations that the time required to achieve permanent hair straightening tends to coincide with the onset of supercontraction, as data in Table II clearly indicate. For example, in the case of 1 N sodium hydroxide, it takes about 15–20 minutes to achieve effective hair straightening. On the other hand, it takes as long as 45 minutes for THP. Closer examinations of the rate of supercontraction show that in sodium hydroxide solution, hair fiber will start to supercontract in 10 minutes, and supercontract completely in about 20 minutes. For THP, it takes much longer for fiber supercontraction to start, and it takes about 40–45 minutes for completion. What this seems to suggest is that radial swelling of the hair fiber is only the initiation step that helps to achieve the necessary uncoiling of the curly fiber into a straight configuration. The primary driving force to impart permanent straightening to the hair is the subsequent supercontraction of the fiber.

THE ROLE OF CYSTINE AND LANTHIONINE

The formation of a new crosslink such as lanthionine is generally believed to be required in hair straightening to stabilize the fiber in the new straight configuration. However, the observations described in Table I would suggest that the formation of lanthionine may not be as critical. Lithium chloride, for example, is not expected to produce any significant amount of lanthionine in the hair, and yet it is able to achieve effective hair straightening under appropriate conditions. On the other hand, 0.1 N sodium hydroxide produces only partial hair straightening, but its action on hair is expected to produce a substantial amount of lanthionine. On analyzing the treated hair samples described in Table I for cystine and lanthionine contents, we were indeed able to show that neither the formation of lanthionine nor the reduction of cystine will always correspond to the efficacy in hair straightening. In addition to lithium chloride, for example, other reagents such as resorcinol, tris(hydroxymethyl)phosphine, and boiling water are all found to be able to achieve effective hair straightening without any evidence of lanthionine formation, as shown in Table III below. Also, a reagent such as dithiothreitol is found to be totally ineffective even though it would cause substantial breakdown of cystine in hair. The assumption that permanent hair straightening requires the cleavage of cystine and the subsequent formation of lanthionine does not appear to be entirely valid.

Table II
Treatment Time Required for Fiber Supercontraction and for Hair Straightening

Reagents	Fiber supercontraction	Permanent hair straightening
Sodium hydroxide, 1 N	15–20 min	20 min
THP	40–50 min	50 min
LiCl	120 min	Over 120 min
Cuprammonium hydroxide	70–80 min	90 min

Table III
Effectiveness of Various Reagents on Hair Straightening

Reagents	pH	Reduction in hair cysteine (%)	Lanthionine formed (%)	Degree of hair straightening
NaOH (1 N)	14.0	35	24	Complete/permanent
NaOH (0.1 N)	13.0	30	17	Partial/temporary
DTT (0.8 M)	3.5	90	0	None
LiCl (40%)	7.0	3	0	Complete/permanent
THP (1 M)	8.5	45	0	Complete/permanent
TGA (1.2 M)	9.6	54	0	Partial/temporary
Urea (50%)	7.0	—	0	None
Resorcinol (40%)	7.0	—	0	Complete/permanent
Boiling water*		5	0	Complete/permanent

* Under tension.

A MODEL FOR HAIR STRAIGHTENING

Based on our observations, it appears that the first step in the process of hair straightening is the uncoiling of the hair curl through the action of radial swelling of the fiber. But it is the subsequent supercontraction of the fiber that determines the success of permanent straightening. If the supercontraction is irreversible, and if the supercontraction is substantial (5% or more), permanent straightening can indeed be achieved. The kinetics of supercontraction is also important in determining the outcome of hair straightening. Permanent hair straightening can be achieved rapidly if fiber supercontraction is fast. These observations suggest that the effect of the fiber supercontraction is essentially to "lock" the fiber in the straight configuration, preventing it from reverting to its native curly configuration. On the molecular level, fiber supercontraction is the result of changes in the secondary structure, involving the so-called alpha-beta phase transition in the organized phase of the keratin (9–11). It is believed that it is the irreversible consequence of these molecular conformational changes that leads to permanent hair straightening. Thus, the cleavage of cystine and the formation of lanthionine are merely by-products rather than prime requirements of permanent hair straightening.

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