J. Soc. Cosmet. Chem., 27, 571-578 (November 1976)

Hair Body

PATRICIA S. HOUGH, B. Sc., J. ELAINE HUEY, B. Sc., and
WILLIAM S. TOLGYESI, Ph.D.*
Presented, May 29, 1975, SCC Seminar, St. Louis, Mo.

Synopsis: HAIR BODY can be defined as the STRUCTURAL STRENGTH and RESILIENCY of a HAIR MASS. The definition conforms to the qualities assessed subjectively by hair cosmetic users. Five groups of fundamental parameters govern the mass structural strength of hair: hair density on the scalp, material stiffness, diameter, configuration of the fibers, and fiber-fiber interactions. The potential influence of hair cosmetics on hair body can be systematically analyzed by deducing their effects on these separate fundamental parameters. It is proposed that current cosmetic products are effective in modifying hair body through only the last two factors: fiber configuration and fiber-fiber interactions.

I. Introduction

Terms like *body* and *texture* have gained greatly in their importance to hair cosmetics during the last few years. All major hair care product categories—shampoos, conditioners, setting aids, sprays, waves, bleaches, and dyes—tend to promise these characteristics to the consumer.

The terms have magic qualities because they represent much sought after properties and because they refer to some intangible characteristics which have not yet been defined. The aim of this paper is to offer a physical definition for hair body, analyze its component parameters, and discuss how different types of products assist in realizing it.

II. Discussion

A. *Definition*

Women tend to judge hair body either by visual or tactile characteristics. According to the visual evaluation, a head of combed-out hair has body if it shows high elevation over the crown and significant lateral displacement at the sides, conversely, when the mass of hair closely follows the shape of the skull on the top and sides under its own weight, it is interpreted as lacking

*Gillette Research Institute, 1413 Research Boulevard, Rockville, Maryland 20850.

body. In tactile evaluation, a mass of loose hair is usually compressed and relaxed, if it is firm and resilient, the rating is positive.

While considerable differences exist both in methods and ratings, a common characteristic can be found in all cases: hair body is associated with mass structural strength and resiliency. On the basis of this, it is proposed that: body is a measure of a hair mass's resistance to, and recovery from, externally induced deformation.

Some of the words of this definition must be emphasized. First, body always refers to a hair mass even if one may extrapolate to it from single fiber properties. Secondly, body is a quantitative characteristic and, therefore, the word measure must be included in the definition. Hair with no body means that some or all of the fundamental parameters which contribute to the mass strength are present at low levels only.

The above definition satisfies the characteristics which are judged by the visual method of body determination according to the following. The emerging angle of hair fibers is high in relation to the skin. Consequently, the fibers would keep pointing in a substantially radial direction with regard to the skull in the absence of outside forces. The continuously acting external modifier is the gravitational force. Depending on the balance between structural strength and resiliency of the hair on one hand, and the gravitational load on the other, the hair mass may show more or less elevation bulkiness. The word bulkiness is used here in terms of its textile definition, meaning low structural density.

In connection with the hand compression method of body evaluation, it is evident that strength and resiliency characteristics are appraised and, therefore, it fits the above given definition for body as well.

B. *Component Factors in Hair Body*

The above definition equates body with the resilient strength of a hair mass under static and dynamic conditions. The resilient strength of any multicomponent engineering structure, which a hair mass is, is influenced by a number of independent parameters. In the most basic form, five such parameters need to be considered: fiber density on the scalp; bending and torsional stiffness and resiliency of fibers; fiber diameter; fiber configuration; and fiber-fiber interactions.

1. *Fiber density on scalp:* Fiber density is an important factor in modifying both structural volume and resiliency of hair mass over and at the sides of the head. When all other factors are equal, the volume of a fibrous mass is a linear function of the number of fibers in it. This correlation is satisfactory to indicate the direction of the influence, but it must not be applied quantitatively to the elevation of hair over the head. The main reason is that the hair mass density decreases with increasing distance from the skin for any fiber density at the roots. The structural stabilization—originating from fiber-fiber

interactions and fiber stiffness—decreases with the density. Complete mathematical models, incorporating all variables, are not yet available. When only the density gradient is taken into account, it is easy to show that the fiber mass elevation increases with the square root of the hair density at the skin level.

The increasing structural resiliency of a denser head of hair can be associated with the following facts: the number of contact points between fibers is higher and the segmental fiber length between supporting contact points is lower. In addition, the angle of contact between neighboring fibers is lower in regions near the scalp. For these reasons, a larger portion of the load is supported by material compression, instead of bending or torsional resistance of the fibers.

The most closely fitting industrial example for the importance of fiber density in a loose fibrous mass is that of a pile carpet. The packing density is of great importance for the resilient strength of these structures.

While the on-head fiber density influences the visual hair body evaluation very strongly, it is probably a secondary characteristic in the hand compresson method which measures intrinsic parameters for the mass structure.

2. *Bending and torsional stiffness and resiliency:* The second group of parameters for hair body involves mechanical characteristics—specifically the modulus and yield stress—of the component fibers in bending and torsional modes. Tensile behavior does not play a significant role in hair body. The weight of even a 100-cm long fiber is in the 10^{-3} g range. This is 3 to 4 orders of magnitude smaller than the yield force of an average fiber in the dry state. However, this load is more than enough to cause torsional and especially bending deformations. The bending deformation gains added importance as it increases with the third power of the segmental length of a beam, which a fiber represents:

$$S = k \frac{f l^3}{M r^4} \tag{1}$$

where S equals bending flexure; k equals numerical constant; f equals force; l equals length of beam; M equals Young's modulus; and r equals radius of beam.

A second characteristic within this group is the resiliency of the fibers, describing the balance between elastic and plastic behavior. Overall, the higher the stiffness and resiliency of the fibers, the higher the body of the hair mass, when other characteristics are equal.

3. *Fiber diameter*: This parameter often reaches a dominant position, because as mentioned before, hair body is associated mostly with torsional and bending deformations of the component fibers. Both the bending and the

torsional stiffness of beams increase with the fourth power of the diameter, as is shown by equations (1) and (2):

$$\theta = k \frac{C\,l}{M\,r^4} \tag{2}$$

where θ equals twist; k equals numerical constant; C equals force couple; l equals length of beam; M equals modulus of rigidity; and r equals radius of beam.

The theoretical value of a sixteen-fold increase in body with a two-fold increase in diameter has been measured by us on certain fiber arrays. This factor is one of the most important in determining natural hair body, both by the visual and tactile methods, because the fiber diameter variation is significant among individuals. Again, carpets provide a descriptive example for this characteristic: fine merino wool is rather unsuited for carpet making in contrast to a coarse South African wool. For equivalent compressive strength and resiliency of a carpet, more wool—by weight—of the former than of the latter type is needed.

4. *Fiber configuration*: The term fiber configuration primarily refers to curliness versus straightness and, secondly, to the array of the fibers. To some extent, the angle of hair fibers relative to the skin belongs to this category. Curly or crimped fibers increase the bulk volume of a fiber assembly; that is, they provide stabilized structures at lower density. An appropriate example is that all bulky knit fabrics rely on crimped fibers. In the case of wool, the crimp is natural, while for continuous filament synthetic fibers, it has to be processed into the yarns separately. Two basic factors are operational when the stabilized bulkiness of a fiber mass is due to curl. One is that a curved object creates a prohibited space—larger than its own material volume—which other bodies cannot easily enter. Secondly, curved fibers establish contacts with larger numbers of neighboring fibers than straight ones. An extreme example for curl induced bulkiness and resilient strength in hair is the natural or Afro style. This cannot be achieved with straight hair without resorting to other stabilizing treatments.

5. *Fiber-fiber interactions:* The last major factor is the surface interaction between fibers, which determines the ease or difficulty of fiber displacement within the mass structure. The structural strength of any multicomponent system, and, therefore, the body of a hair mass, depends on the effective stabilization of the component units relative to each other. When applied to hair, this overall parameter includes a number of basic factors: material frictional characteristics and surface roughness of the fibers themselves, lubricity, shear resistance, and the adhesiveness of any surface coatings under the static and dynamic conditions operating on a hair mass. It is safe to state that the stronger the surface interaction between contacting fibers, the higher the hair body.

In our view, the concept of hair body, as defined above, is exhaustively described by these five variables. The variables are causatively independent of each other, but synergism can exist. For example, fibers of higher material moduli or larger diameter can enhance the structure stabilization by surface interaction as well, because they are able to support higher normal forces. This, in turn, results in greater frictional immobilization.

According to the above given interpretation of hair body, none of the five variables have exclusive influence on the overall behavior. Therefore, any specified level of body, if a quantitative scale existed, could be obtained by a nearly infinite number of variations among the five factors. Obviously, when a given body level is achieved by different combinations of the fundamental parameters—for instance, a decreasing fiber diameter is balanced by increasing hair density—some other perceptible hair mass characteristics will change. These changes, however, belong to second-order behavior patterns, specifically to texture qualities.

C. *Cosmetic Products and Hair Body*

The specific influence of cosmetics on hair body is best discussed by analyzing the changes in the five basic parameters caused by different cosmetic products.

It may be stated summarily that cosmetics—according to the current definition of the term—cannot directly influence any of the five parameters so far as the biological synthesis of the fibers is concerned. Compositions or treatments which could grow denser, stronger, thicker, curlier, or rougher hair would be outside the field of cosmetics. Therefore, the discussion needs to involve only those effects of cosmetics which occur on grown hair.

Cosmetic products can have only indirect and/or negative effects on fiber density. The on-head fiber number can be considered as a kinetic equilibrium determined by the rate of new fiber growth on the one hand and the rate of fiber elimination on the other. As mentioned above, fiber growth rate is not a cosmetically solvable problem. The rate of fiber attrition, however, can be influenced to some degree. Treatments or products, which result in more difficult combing, accelerate the rate of fiber elimination, thereby reducing the fiber density to a lower steady-state level. Lubricants, on the other hand, delay the mechanical fiber removal and assist in the maintenance of marginally higher fiber densities. Nonetheless, these effects are secondary, and it may be stated that cosmetics do not significantly influence hair body through modification of the fiber density on the scalp.

The modulus or stiffness of polymeric materials can be increased by chemical treatments. This has been achieved on natural fibers, including keratin fibers, by cross-linking, or by introducing bulky side groups. However, the nature of the reactants and/or the reaction conditions are such that, at present, these methods cannot be used for on-head treatments. No current cosmetic products increase body by this method. Conversely, some cosmetic products decrease the level of cystine cross-links in hair. These include bleaches and especially bleaches followed by permanent waving. Their influence on the dry modulus—and on whatever segment of body is derived from the modulus—is negligible, because the cystine cross-links are not important load bearing elements in dry fibers within the Hookean range

The moduli of the fibers can be influenced by internal or external deposition of nonreactive materials as well. The resulting systems are composite structures with increased final fiber volumes, therefore, these will be discussed in connection with the fiber diameter effects.

A specific case of modulus change occurs when the hair is swollen by liquids which interfere with the internal salt and/or hydrogen bonds of the fibers themselves. Wetting of intact hair by water decreases the modulus by nearly an order of magnitude. The wet modulus of an oxidatively modified hair is even lower. While the modulus reducing effect of fiber swelling liquids must be kept in mind when hair compositions are formulated, the fact in itself is of little importance for the present purpose. Hair body refers primarily to the dry and not to the wet state of the hair. The overly high softness of extensively bleached or bleached-waved wet hair may present problems during a shampoo and wet comb-out, but it does not translate to the dry behavior. Overall, it may be concluded that present day cosmetic products and processes can influence hair body only marginally through modulus modification.

Body modification through fiber diameter increase can be accomplished by internal or external deposition of foreign materials. High levels of internal polymer deposition have been accomplished both on wool and cut hair, with significant increases in body type characteristics. While processes are available for the deposition of solids, mostly polymeric materials, they are not presently utilized in cosmetic products for reasons already mentioned. On the other hand, materials of small molecular weight which are sorbed by the hair —such as alcohols, amines, etc.—most often act as plasticizers, therefore, defeat the original purpose of increasing body.

Only solid materials need to be considered for external deposition which can act as load bearing elements. While setting lotions and gels meet this requirement, the approach has serious limitations. The coating thickness must be very limited, if the natural fiber surface and topography are to be maintained. Consequently, hair body can be increased by surface deposition only if the coating is continuous and its stiffness is significantly higher than that of the fibers. In this case, the composite material—keratin core and external coating—has high bending stiffness. A specific case is when the solid deposit acts as an adhesive on heavily surface damaged fibrillated fibers. Through adhesively joining these splintered surface units to the main fiber body, they recover their load bearing ability in fiber deformation.

Based on the above, it can again be concluded that current cosmetic products do not increase hair body significantly by increasing the diameter of the fibers. Even in the case of setting gels, the effectiveness is not due primarily to this parameter.

Fiber configuration and array represent an area through which hair body is often increased. The higher the curl level and the greater the disorientation of the fibers, the greater will be the bulkiness and, thereby, the body. Permanent waving solutions and setting lotions and gels operate by this mechanism. All wet hair treatments can operate through this method, as they provide the opportunity for obtaining a temporary water set in the desired configuration. Prior chemical treatments, such as bleaching or waving, which increase the fiber swelling in water improve the water settability further and, therefore, increase the temporary body characteristics. For the sake of completeness, it must be mentioned that some hair care appliances (i.e., curling devices and even hand-held driers) belong to this category. Hand-held driers, in the normal mode of operation, provide water set to the hair at a high angle relative to the skin and reduce the level of configurational conformation among neighboring fibers.

The factor through which cosmetic products most often influence hair body is the fiber-fiber interaction. No cosmetic treatment leaves the fiber surface unmodified relative to its starting condition.

The products which most drastically increase hair body by this mechanism are sprays and polymeric setting lotions. These form rigid joints between contacting fibers which are similar to welding in steel structures. In order to overcome the segmental stabilization of involved fibers, the joints must be broken. Even when this is achieved, subsequent fiber displacement is still resisted as long as laterally extending asperities of the broken joints remain on the fibers. Therefore, the structural strength of a sprayed hair mass decreases with comb-out, but does not sink back to its original presprayed level until the residues are fully removed, for instance, by shampooing. The opposite case—a lowering of body—can be accomplished by surface coating when the deposit is a lubricant with low static frictional coefficient. Quaternary ammonium components behave this way. The shear strength of fiber joints is very low in this case, therefore, the fibers will displace, even under very low external forces and occupy lower-energy positions. With this treatment alone, a bulky high-bodied structure cannot be achieved when all other parameters are equal. Other surface deposited materials can achieve intermediate positions between these extremes. Generalizations, according to conventional classification of materials, must be avoided. Oil, grease, and wax-type components of shampoos, rinses, and conditioners, which are lubricants in the everyday use of the word, can increase hair body. They form adhesive joints between contacting fibers with finite well measurable strength. The bonding strength derives both from surface tension and from static shear rigidity of the thin films. The kinetic frictional resistance of these joints is often low, allowing easy combing, but their static strength is considerable—in the range of a few milligrams. The layer thickness, especially for long hair, must be controlled because, in the case of overloading, the hair mass may compact and settle under its own weight. Chemically active hair cosmetics—bleaches, permanent waves and oxidative dyes—increase the material frictional coefficient and the surface roughness of the fibers and thereby reinforce the fiber-fiber interactions. This results in increased body.

III. Conclusions

It is possible to assign physical interpretation to a cosmetic term such as hair body which is logical and self-consistent in scientific meaning and correlates with the linguistic use pattern of the word. Furthermore, it is possible to break down the complex body characteristics into fundamental, single parameter, physical factors. The body attributes of hair cosmetics can be studied systematically, by evaluating their effects on these fundamental factors. It is, of course, quite easy to design measurements for directly assessing the influence of cosmetics on the complex phenomena, and we have used such techniques for body determination for some years.

Obviously, the present discussion represents a single viewpoint and further discussions by individuals from different areas of the fiber and cosmetic fields would be highly desirable to achieve a consensus on, and a better definition of, these rather important terms.

(Received June 3, 1975)