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A Quantitative Characterization of Combing Force

WALTER NEWMAN, M.S.,* GEORGE L. COHEN, Ph.D.,† and CLETUS HAYES†

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Synopsis—A quantitative method for measuring and comparing the effect of various cosmetic treatments and products on the amount of FORCE needed to COMB a tress of HAIR is described. Photographs of the apparatus and a detailed description of the experimental procedure are provided. The results of several experiments evaluating the effects of several commercial hair conditioners, bleaching, and various "texturizing" resin-containing formulations are also summarized.

Introduction

The use of conditioners, specifically quaternary ammonium compounds containing one or two long alkyl chains, to treat hair so that it is easier to comb, especially after washing, is a well-known process which has long been of great commercial importance, as evidenced by the number of products sold for this purpose. The methods used in the laboratory to study the conditioning of hair have generally been subjective and qualitative, involving panels and trained observers. The purpose of the work described in this report was to develop a quantitative and reproducible method of measuring the force required to pull a comb through a tress of hair in order to determine the effect of products or processes intended to condition or otherwise cosmetically treat hair. Additionally, the ability to make such quantitative and reproducible measurements would be essential in any study attempting to understand the nature of the physical-chemical factors involved in hair conditioning.

There have been many reports describing the surface structure of wool and the properties of this keratin fiber resulting from these structural features (1,

*Present address: Johnson & Johnson Research Center, U.S. Rt. 1, North Brunswick, N.J. 08902.

†Department of Physical Chemistry, Bristol-Myers Products, 1350 Liberty Ave., Hillside, N.J. 07207.

2). Over the past few years, investigations of the surface of hair (3) and of various properties of hair due to the nature of this surface have also been reported. Schwartz and Knowles, utilizing techniques developed during studies of wool, measured the friction of single hair fibers against a variety of surfaces (4). Nagai and coworkers measured hair-hair friction (5). In another study, reported by Waggoner and Scott (6), the amplified audible noise resulting from combing was used as a measure of conditioning.

Each of these papers described investigations of only one of the parameters involved in combing. The actual force of combing, however, would be expected to depend upon a number of interrelated factors which would determine the nature and extent of the fiber-fiber and fiber-comb interactions. The method described in this report was developed to study the total of all of these interactions, i.e., the force needed to comb a hair tress.

Experimental

A photograph of the apparatus used to measure the combing force is shown in Fig. 1. Figure 2 is a simplified schematic diagram thereof. A strain gauge transducer* (maximum range = ±680 g†) was attached to a lift mechanism operated by a synchronous motor and positioned directly above a rigidly fixed comb. A hair tress of the proper weight was prepared by attaching the test hair at the root end to a stainless steel dowel with a rubber band.

Before the measurement, the dowel was placed in a slot, thereby positioning the tress directly below the transducer. A side view of the tress in place with the hair strands not yet in the comb teeth is shown in Fig. 3. The upper portion of the tress is supported by a hard rubber bar made of the same material as the comb through which the hair is to be pulled (in this case, the back of another comb was used). The comb was then slowly raised into a horizontal position by gently pushing on the "comb rod" while the hair strands were evenly distributed between the comb teeth (Fig. 4).

With the tress in place, the voltage output from the transducer was nulled electronically and the motor turned on so as to pull the hair through the comb. After less than a second, the force reached a nearly constant value. Although several preliminary experiments showed that a wide variation in the speed with which the tress is pulled through the comb does not change the measured value of the force, the motor was adjusted so that the tress was being lifted at a rate of 1.5 mm/sec.

Either "wet combing force" or "dry combing force" was measured depending on the use conditions of the product or material to be tested. In all cases,

*Stratham Instrument Co. of Puerto Rico, Cat. No. GI-24-350.

†Units of mass (grams), rather than force (dynes), are used in this paper to represent combing force, since it was considered that this would give the reader a better grasp of the magnitudes of the forces involved in the combing process.

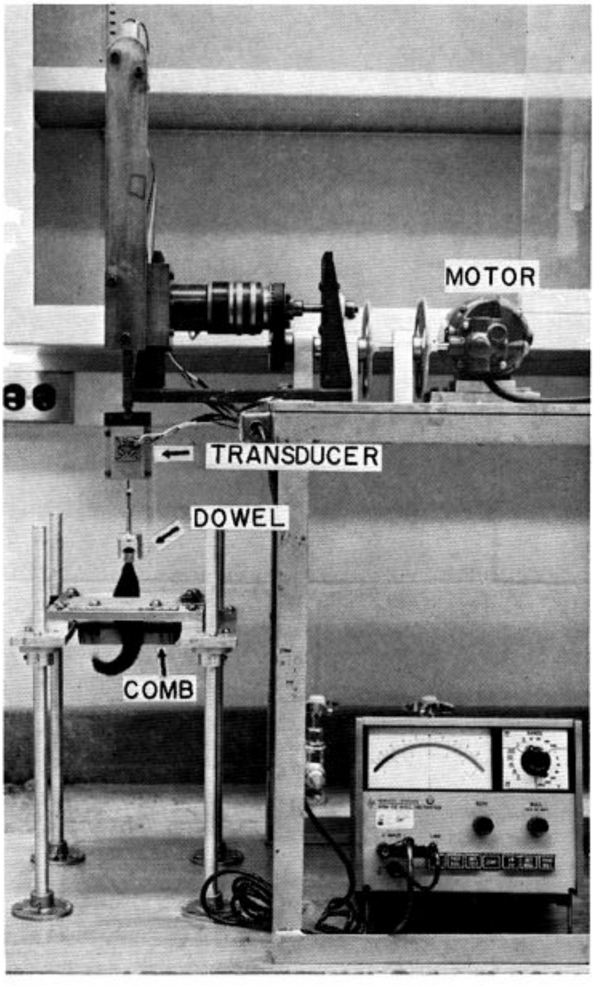

Figure 1. Apparatus used to measure combing force

each tress was used as its own control. For wet combing, the method was as follows: A tress weighing about 2.75 g* was prepared from dark brown European hair.† The tress was washed in a 15% sodium lauryl sulfate (SLS) solution, rinsed, rewashed, thoroughly rerinsed to remove all traces of SLS, and combed to remove all tangles. The combing force was then measured 5 times, the tress rinsed again briefly with distilled water, the combing force remeas-

*All weights reported have been corrected for the weight of the dowel and rubber band.

†Purchased from either De Meo Brothers or Alfred Klugman, Inc., both of New York City.

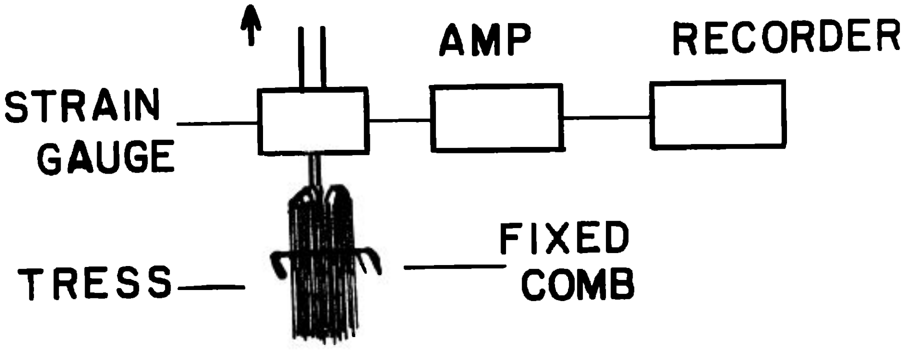

Figure 2. Schematic diagram of combing force apparatus

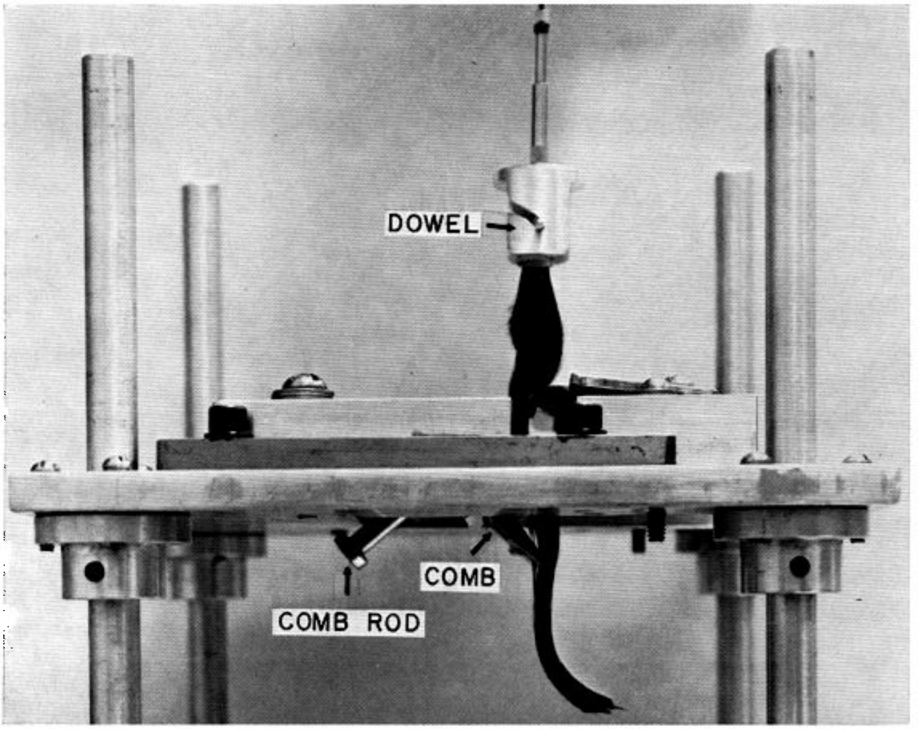

Figure 3. Close-up view of tress prior to insertion of its strands between the comb teeth

ured 5 times, the tress rerinsed, etc., until up to 25 measurements were made. The tress was treated with the test material and then combed extensively to ensure the even distribution of the latter throughout the tress. For certain

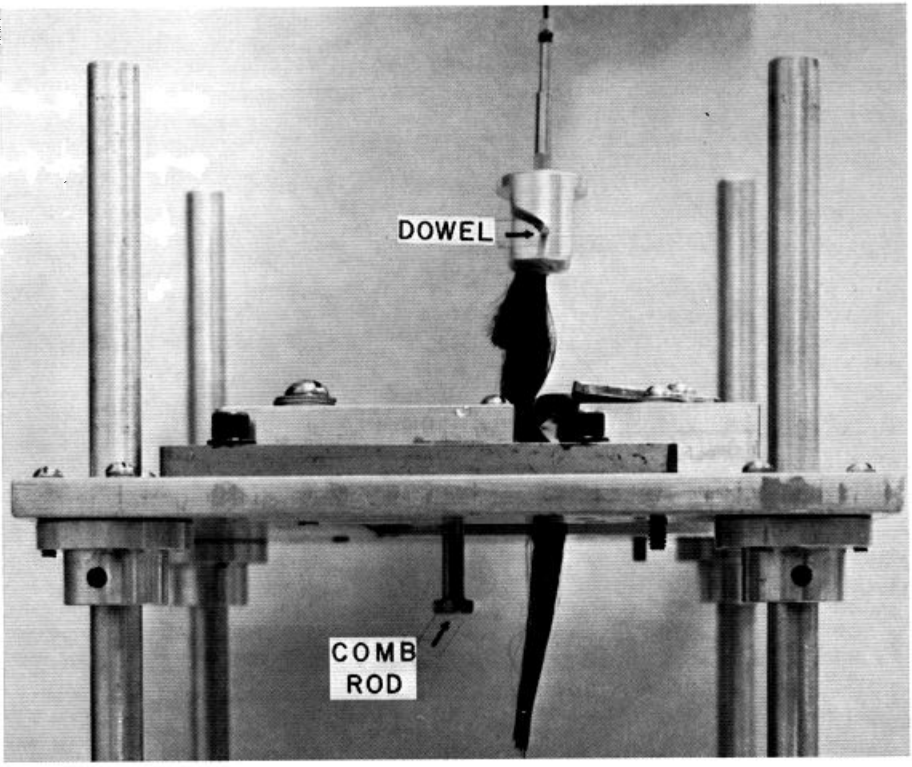

Figure 4. Same view as Fig. 3 after the strands have been inserted in the comb

"creme rinses," label instructions required further rinsing at this point. This was done when necessary. The combing force was again determined and the results reported as "per cent residual combing force," calculated as:

$$\frac{\text{combing force of treated tress}}{\text{combing force of tress prior to treatment}} \times 100.$$

For measurement of the "dry combing force," tresses weighing approximately 4.75 g were used, with each tress being dried with a warm air hair drier before each series of measurements.

For both wet and dry hair, care was taken by the operator to distribute the strands of hair in an even and reproducible manner between the teeth of the comb. It was also found necessary to use each tress as its own control and to repeat each measurement from 15 to 25 times. Despite these precautions, the average values of the per cent residual combing force were found to have a standard deviation of up to 20%. This procedure was therefore unable to detect small changes in combing force upon cosmetic treatment.

Table I
Comparison of Wet and Dry Combing Force[a]

	Force (g)	
Tress No.	1	2
Dry	12 ± 3	13 ± 2
Wet	95 ± 20	88 ± 5

[a]Tress weight = 4.75 g.

Table II
Effect of Conditioners on Wet Combing Force

	Combing Force (g)			
Product	A	B	C	D
Before treatment	59 ± 7	54 ± 5	51 ± 7	51 ± 4
After treatment	38 ± 3	41 ± 5	37 ± 4	23 ± 3
Residual, %	64	76	73	45

Results

The results of wet and dry combing force measurements of each of two tresses are compared in Table I. In this experiment, the tress weights were approximately 4.75 g. Reproducibility of the measured wet and dry combing forces for each tress is typical for this procedure, as discussed above. It can be observed that the wet combing force is much higher than the dry combing force of the same tress. Possible reasons for this will be discussed below.

Table II lists the reductions in wet combing force found after application of 0.2 ml of 4 commercial hair conditioners. The results are the average of at least 25 measurements on several tresses for each product. In accordance with label instructions, the tresses treated with A, B, and C were rinsed with distilled water before measurement. In each case, the rinsing lowered the residual combing force significantly. Product D, which gave the largest reduction of combing force, was used in further studies.

A comparison of the reduction of wet and dry combing force resulting from use of Product D is found in Table III. The wet combing force of the hair after conditioning was reduced to approximately one-half of its initial value, while the dry combing force showed little, if any, significant decrease.

The effect of amount of conditioner applied is illustrated in Fig. 5. An equal volume, 0.2 ml, of each of several aqueous dilutions of conditioner D was applied to each tress. The calculated value of the standard deviation is included with each experimental result. There was a decrease in the degree of reduction of combing force as the product is diluted; however, even at high dilutions, the effect still appears to be significant.

Table III
Comparison of Effect of Conditioner on Wet and Dry Combing Force

	Dry Force (g)	Wet Force (g)
Before treatment	12.5 ± 2	51 ± 4
After treatment[a]	10 ± 2	23 ± 3
Residual combing force, %	80	45
Tress weight, g	4.75	2.75

[a]Tress treated with 0.2 ml of conditioner D.

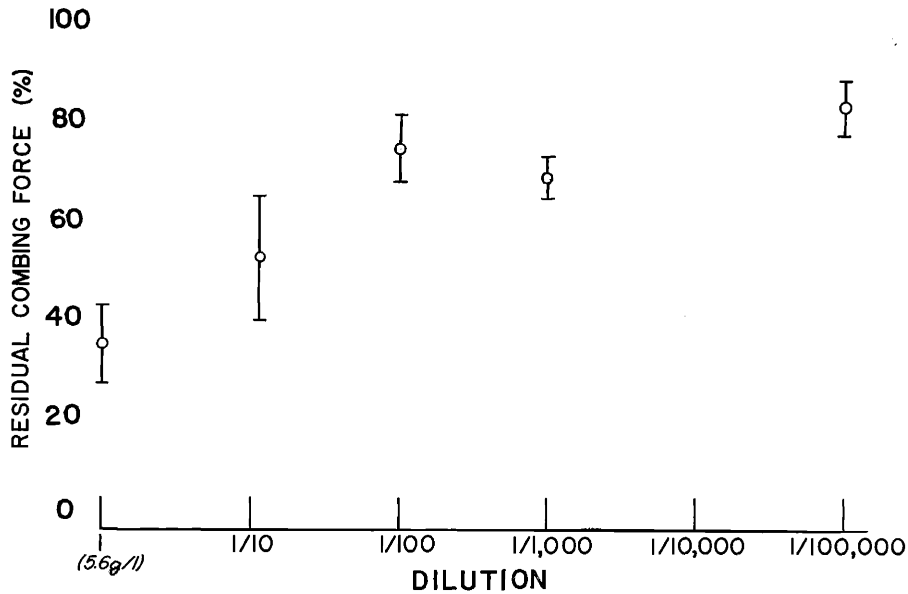

Figure 5. Relationship of residual combing force to amount of conditioner

Table IV compares the effects of several resins used in experimental men's hair grooms. These materials, intended to "texturize" hair by thickening it and adding "body," increased the combing force. In the cases illustrated, dry combing force was determined. The resins were tested both as applied from aqueous solution and from specific hair groom formulations.

Table V summarizes combing force measurements done on bleached hair. The wet combing force was determined for two tresses, which were then bleached once or twice for 30 min by immersion at room temperature in a solution prepared by dissolving 24 g of a mixture consisting of 62% potassium persulfate, 21% ammonium persulfate, 14% sodium silicate (the remainder being flowing, chelating, and wetting agents) in 50 ml of 6% hydrogen peroxide;

Table IV
Effect of Resins on Dry Combing Force[a]

Resin Type	3% Aqueous Solution		Prototype Formulation	
	Combing Force (g)	Residual Combing Force (%)	Combing Force (g)	Residual Combing Force (%)
Cationic	31	200	21	150
Carboxylated	34	240	35	250
Vinyl	24	170	27	190

[a]Average control force = 14 g.

Table V
Effect of Bleaching on Combing Force

Experiment No.	Initial Force	No. of Bleach Treatments	After Bleaching	After Conditioning
1	80 ± 12	1	225 ± 30	50 ± 10
2	75 ± 5	2	320 ± 50	75 ± 15

the pH of the solution was 9.4. Tensile strength measurements of the bleached hair were made on a model TM-M Instron* by determining the F_{15} of individual hairs before and after bleaching (7). The tensile strength of the hair bleached 30 min was reduced to approximately 85% of its initial value, while that of the hair bleached for 1 hour was 70%. As summarized in Table V, the bleaching caused a large increase in the wet combing force of the hairs. When the tresses were treated with 0.2 ml of conditioner D, a large decrease in the combing force resulted. Although both of these effects have long been known to formulators and consumers alike, the above data represent a quantitative determination of their extent.

Discussion

The interaction of water with hair and wool and the effects of this interaction on the properties of the fibers have been studied and documented for many years (8, 9). Two of these interactions that must be considered in trying to understand the much larger amount of force needed to pass a wet tress of hair through the teeth of a comb are discussed below:

a) The saturation of hair with water will increase its diameter by approximately 14% above that found at an ambient relative humidity of 30 to 40% (9, 10). Therefore, wet hair would occupy that much more volume and be expected to offer more resistance to the passage of the comb. The quantitative effect of swelling on the combing force could be deter-

*Instron Corp., Canton, Mass.

mined by studying tresses placed in both swelling and nonswelling liquids. However, the 14% volume increase caused by water is probably not responsible for more than, at most, a small percentage of the increased combing force of wet hair (Table I), for the combing force of a wet tress weighing 2.75 g is found to be greater than that of a dry tress weighing nearly twice as much (Table III).

b) It is obvious, even to the casual observer, that the strands of hair in a wet tress tend to cling together, so much so that it is often somewhat difficult to separate a single strand from the others. The amount of force necessary to overcome this interaction by the comb teeth must be a part of the higher wet combing force.

Other, as yet unknown, interactions are also probably involved.

The effects of quaternary ammonium compounds containing one or two long alkyl chains that are discussed in this report have long been known and these materials have been widely used to soften textile fibers and fabrics during processing and washing and to condition hair after shampooing (11–13). A great deal is known about the rate and mechanism of sorption of these materials onto hair and textiles (14). Much has also been learned about the surface structure of keratin fibers and the effect of this structure upon their properties (1, 2). Nevertheless, at present, there is no complete picture of the mechanism of the conditioning process and of how these materials so dramatically affect the "feel" and combing properties of hair.

In 1971, Finkelstein and Laden described an investigation of the effect of various hair conditioners on the ease of combing (evaluated subjectively) when used both above and below the critical micelle concentration (15). They studied the effect of chain length of cationic used and interpreted their results in terms of surface adsorption of the conditioner and the formation of two-dimensional "hemi-micelles" on the hair surface. To the best of our knowledge, no further investigations developing upon these results have been reported.

It is hoped that future studies, using the procedure described in this report and/or the many techniques now available for studying fiber friction and surface properties (including scanning electron microscopy), will elucidate the nature of the conditioning process.

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