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Combability Measurements on Human Hair

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Synopsis: An instrumental method for MEASURING the effect of cosmetic products or any other treatment of the COMBABILITY of HUMAN HAIR has been developed. The required instrumentation, experimental procedure, and interpretation of the data are presented in detail. The method involves the continuous recording of the forces, which oppose the motion of a comb through a swatch of hair. The data thus produced consists of graphs showing the forces opposing (or generated by) combing as a function of the position of the comb along the length of the swatch. Examples of applications are presented.

Introduction

Combability can be defined as the subjective perception of the relative ease or difficulty with which human hair can be combed. It depends on the magnitude and on the fluctuations of the forces that oppose combing.

Combability is an important attribute, which is always considered when judging the "condition" of human hair. Improved combability is perceived as the hair being in better condition. Another concept closely associated with combability is that of manageability. Still another factor related to combability is that of the mechanical damage, which is done to hair with the combing process, which is accelerated if the hair is hard to comb or to untangle. It follows that combability, due to its close connection with other desirable hair qualities, is a very important factor in judging the performance of many hair care products.

The method described in this paper was developed in our laboratories for the purpose of quantitatively evaluating combability. It has been extensively tested with a wide variety of hair products and treatments and is now used as a standard test during product development and for claim substantiation in finished products. A number of instrumental methods for evaluating combability have been reported in the literature (1–3). Some of the similarities and differences between those methods and ours will be discussed later. It is our opinion that our method has advantages in its simplicity and in the type of information that can be obtained by using it.

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In what follows, the method is first described in full detail so that it can easily be used by any interested laboratory. This description is followed by a selected number of experimental results, interpretation of the data, and a general discussion of the method.

Method

Experimentally, the method consists of suspending a hair swatch from a force-measuring device, inserting a comb close to the root end of the swatch, setting the comb in a straight combing motion through the swatch at a constant speed, and continuously recording the forces that resist its motion during this transit from the point of insertion till it clears the tip end of the swatch. The data resulting from this operation consist of a graph showing the load (in grams) opposing (or generated by) combing as a function of the position of the comb along the length of the swatch. We call this graph a 'Combing Curve.'

Combing curves can be recorded using dry or wet hair. Typical examples of these curves can be seen in Fig. 1 (dry) and Fig. 2 (wet). Dry combing curves are recorded using swatches, which have been previously hand combed. In spite of the precombing, they show gradually increasing combing forces which reach maximum values at or near the tip end of the swatch. Wet combing curves are recorded using swatches which have been purposely tangled by immersing them in water. The resulting curve shows a high incidence of tangles all through the length of the swatch. In some cases, the combing forces are higher close to the tip end of the swatch.

In our method, combability is measured by means of two parameters, which can be directly obtained from the combing curves. The first parameter is 'peak combing load' (PCL). This is the highest load (in grams) that is recorded during the combing of the swatch. Points P in Figs. 1 and 2 are examples of PCLs. If desired, PCL can be converted to peak combing forces (PCF) (in dynes) by multiplying them by the acceleration of gravity ($\approx$980. cm/sec^2). The second parameter is the average combing load (ACL). This is the average load during one combing of the swatch. It is expressed in grams • cm units) by the distance in centimeters traveled by the comb through the swatch.

Both of these parameters give us a quantitative measure of how difficult (or easy) it is to comb a swatch of hair. Our method is based on measuring the changes that occur in such parameters when the hair is treated with a product. Decreases in PCL and/or ACL, which indicate improvements in combability (and vice versa) correlate with what is perceived when the hair is combed by hand.

As could be expected, the absolute values of the PCLs and ACLs depend on a large number of factors such as speed of combing, handling of the hair, dimensions of the hair swatch, curliness of the hair, comb dimensions, comb material, etc., which cannot be totally controlled. It is for these reasons

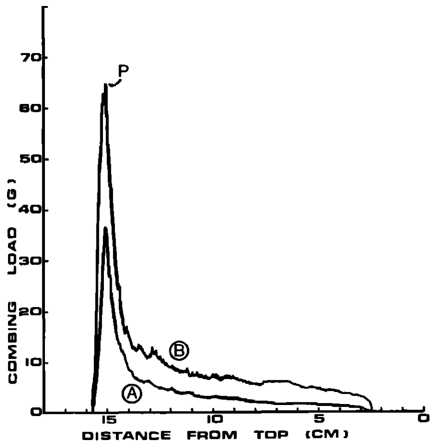

Figure 1. Dry combing curves, B before treatment, A after treatment with commercial creme rinse. Combing loads appear plotted against distance of comb from top end of swatch

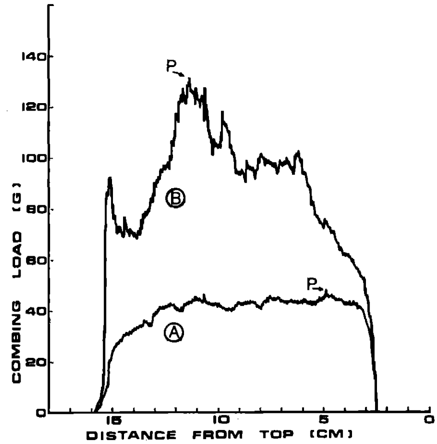

Figure 2. Wet combing curves, B before treatment, A after treatment with commercial creme rinse. Combing loads appear plotted against distance of comb from top end of swatch

that changes in the values of these parameters are more important and more reproducible than their absolute values. It also follows that great care has to be taken so that comparisons—as, for example, before and after the use of a product—are done under experimental conditions that are, insofar as possible, identical. If done carefully, however, this method allows us to measure changes in combing forces of the order of ± 20 per cent. Average changes are calculated by averaging the individual values measured on a set of replicate swatches.

Equipment

The instrumentation consists of an Instron Tensile Tester (Metric Table Model, TM-M*) to which some attachments have been added (see Fig. 3). The Instron load cell B which has a range of 0 to 2,000 g is used. Other recording tensile testing instruments could be similarly adapted.

The attachments to the Instron Tester shown in Fig. 3 are as follows (c) Comb Stand: the comb stand is an L-shaped aluminum part designed to hold different types of combs, it is mounted on the traveling crossbar of the Instron by means of two screws; (b) Comb: the comb used in our measurements consists of 8 cylindrical stainless steel teeth (unpolished), 2.2 mm in diameter, mounted (with an interteeth distance of 1.5 mm) on an aluminum frame. Two removable bars of the same material and diameter as the teeth are

*Instron Corp., Canton, MA.

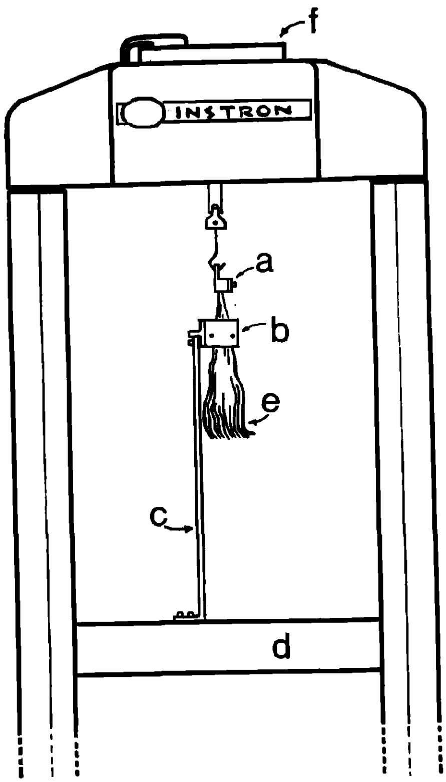

Figure 3. Part of Instron Tensile Tester showing combing attachments: (a) clamp; (b) comb; (c) L-shaped stand; (d) crossbar; (e) hair swatch; (f) load cell

mounted perpendicular to them in order to keep the hair in place during combing (Fig. 4). (a) Clamps: the hair as used for these measurements is mounted on specially designed aluminum clamps (Fig. 4). These clamps produce approximately rectangular cross-sectional swatches .They have a hole on the top from which they are hung on a 1.5 mm diameter metal rod, which is connected to the load cell of the Instron. At the clamp, the dimensions of the cross-section of the hair swatch are 2.8 cm in length and approximately 2 mm in width. At least two regular hand combs should be at hand for each measurement. One of the combs should only be used for clean untreated hair swatches. The other one should be used for the treated swatches. Ordinary hard rubber or nylon combs are suitable.

The measurements are done under standard temperature and humidity conditions ($70 \pm 2°F$, 65 ± 2 per cent RH). This requires the availability of a temperature and humidity controlled room wherein the tensile tester can be located and operated.

Sample Preparation

The preparation of swatches consists of mounting the hair that has been selected to be used in the measurements, on the clamps previously described. The uniformity of this operation is facilitated by proceeding as follows: start by securing enough hair for a complete set of measurements. Six swatches are recommended in routine evaluations of products. If changes in combability are very small, more swatches might be required to ascertain statistically significant changes. About 10 g of hair are required to prepare each swatch. Although if could be desirable to use perfectly straight hair, this is not practical because it is difficult and expensive to obtain such hair. Virgin European hair with its natural soft curl is perfectly suitable for these measurements and should be used.

If possible, all the hair to be used in 1 set of measurements should come from the same batch of commercially purchased hair. Blending the hair is not necessary and is not recommended because the coherence of the hair's natural curl is lost, and this results in excessive tangling.

The length of the individual hairs to be used should be uniform. A good length to start with in preparing swatches is 11 in.

Measure the length of the hair in inches. On a top loading balance weigh (to ± 0.2 g) individual bundles of hair (one for each swatch) so that each

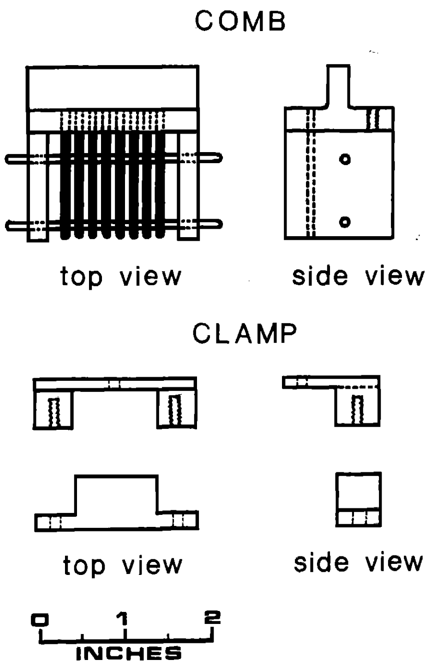

Figure 4. Top and side views of comb and clamp used in measurements

bundle's weight in grams is approximately equal to its stretched length in inches times (0.7); that is, the linear density of each bundle should be approximately 0.7 g/in. Handle the bundles gently so that the hair's natural curl is not unnecessarily disturbed.

Place the rootend section of a bundle in the throat of the clamp and distribute the hair evenly throughout its width. Allow approximately 1 in of hair beyond the throat of the clamp. Secure the male part of the clamp to the other part by means of the 2 screws. Proceed in the same way with the rest of the bundles. Cut the excess (root end) hair close to the top of the clamp's jaws. Stretch the hair swatch with the hands and cut the tip end of the hair at a distance of 6.5 in. from the closest end of the clamp. This can be done conveniently using a laboratory guillotine.* The amount of hair freely hanging from the clamp will weigh 4.5 to 5.0 g.

The hair mounted on the clamps should be cleaned in order to remove dirt, grease, or any foreign material that might be present on the hair when it is purchased. The cleaning is done using a 15 per cent aqueous solution by weight of sodium lauryl ether sulfate. The (unadjusted) pH of this solution is in the range of 7 to 8. The solution is liberally applied twice to each swatch as if it were a shampoo. After the second application, the swatches are thoroughly rinsed under running deionized water (at room temperature) for 30 min. For our purposes, this cleaning treatment is more realistic and less arbitrary than the commonly used precleaning of hair with various organic solvents.

After cleaning, the swatches are combed and hung to dry and equilibrate to the standard conditions of 70°F (21.1°C) and 65 per cent RH for 24 hours in a controlled environment room or chamber.

Experimental Procedure

The experimental procedure consists of measuring the PCLs and/or ACLs of the same hair swatches wet and/or dry before a treatment and after the treatment.

Measurements on Untreated Hair—Wet Measurements as follows. Step 1: turn on the Instron, allow it to warm up, and calibrate, following its operation manual. Step 2: place each of the swatches to be measured in deionized water at room temperature (70°F) for at least 10 min and for no more than 30 min prior to the measurements. This can be done by supporting the swatches by the clamps and allowing them to hang freely inside a large beaker ($\approx$ 3000 ml) full of deionized water. Step 3: take the first swatch out of the water and comb it until no detangling is noticed on further combing. Start this operation using

*Harvard Apparatus Co., Inc., Dover, MA.

the wide-tooth section of a hand comb and finish using the thin-tooth section. Step 4: immerse the hair swatch 3 consecutive times in a separate beaker containing deionized water at room temperature. The purpose of this step is to generate a certain degree of tangling of the swatch under controlled conditions. This step is very important and care should be taken to perform it in the same way each time. It should be done by holding the swatch through the clamp and gently dipping it in and out of the water 3 times. After the third immersion, squeeze out the excess water twice with the fingers. Step 5: with the crossbar sufficiently out of the way (below), hang the hair swatch from the load cell hook and adjust the pen of the recorder so that the swatch plus the clamp read zero. To do this, use the balance control of the recorder, which does not affect its calibration. Step 6: remove the swatch from the load cell and hang it by its clamp close to the Instron. Displace the crossbar upward to the starting position. At this point, the teeth of the comb should be at a distance of 2.5 cm from the lower edge of the hair swatch clamp. Step 7: hang the hair swatch from the load cell, and using two fingers to flatten the swatch, push-guide the hair into the comb. If done carefully, this operation insures a fairly even distribution of the hair between the interteeth spaces. Also, because the width of the swatch at the clamp is 2.8 cm, and the distance between the 2 outer teeth of the comb is 3 cm, it is simple to have all the hair "in" the comb. Place the thin metal rod below the teeth, perpendicular to them, to prevent the hair from coming out of the comb during the measurements. Step 8: once the hair is properly placed in the comb, the actual measurement can be started. This consists of continuously recording the force that is required to move the comb down through the hair swatch at a constant speed. This is done by setting the crossbar in downward motion while continuously recording the load. If a recorder integrator is available, it should be functioning so that the area under the combing curve is measured. The combing speed will be set at 10 cm/min and the chart speed at 10 cm/min. The sensitivity for the recorder will be set according to the values of the forces encountered. Step 9: repeat steps 4 through 8 twice for the same swatch in order to record triplicate runs. Step 10: repeat steps 2 through 9 for the remaining swatches. Step 11: after the wet measurements are completed, comb the swatches using the hand comb, hang them through the clamps and allow them to dry and condition for at least 24 hours at 65 per cent RH and 70°F.

Dry Measurements: Dry measurements comprise steps 12 and 13. Step 12: Start the dry measurements by taking the first conditioned hair swatch and combing it with the hand comb until no detangling is noticed on further combing. Proceed then with steps 5 through 9 as before. Step 13: repeat step 12 for the remaining swatches.

Treatment: Give the treatment to the hair mounted on the clamps following the recommended instructions for the product. Use deionized water whenever water is needed. The amount of product to be applied to each hair swatch is calculated taking into account the amount recommended for a head of hair, using 100 g of hair as the average weight of hair for adult females, and weight of hair in each hair swatch. The following formula is applied for this purpose.

$$\text{Weight of product to apply per swatch} = \frac{(\text{weight of hair swatch}) \times \left(\begin{array}{c}\text{Amount of product}\\ \text{recommended for a}\\ \text{head of hair}\end{array}\right)}{100}$$

If rinsing with water is the last step of the treatment, care should be given to this operation. Rinsing should be sufficient to eliminate excess product, but not so intense so that the effect of a product could be completely eliminated. The way in which the product is used in actual practice should be followed. For example, shampoos are rinsed until foam is no longer evident; the same should then be accomplished with the rinsing given to the hair swatches. Once the conditions are specified, care should be exercised in rinsing each of the swatches in the same way. Rinsing conditions should specify volume of water, temperature of the water, rinsing time, and method (flowing water or immersion).

Measurements of Treated Hair: Wet measurements on treated hair should be done right after the treatment, preceded only by a 5-min period in which the treated swatch is allowed to relax immersed in water. The rest of the wet treated swatches should be left hanging from their clamps while they wait for the 5-min relaxation period and subsequent measurement. The main reason for doing the wet measurements right after the treatment is because, in practice, the hair has to be combed after any treatment, and it is at that point that the user will associate the product with its effect on wet combability. Obviously, wet measurements can be done at a later time if this will contribute additional information on the effect of the product.

Calculations

Once the measurements are completed the data required to calculate changes in combability are obtained from the combing curves.

The PCL for each run corresponds to the highest load recorded for that run and is read directly from the corresponding combing curve. The load for a full-scale deflection use for recording obviously has to be taken into account.

The ACL for each run is calculated by first measuring the area under the corresponding combing curve (in grams cm • units) and then dividing the value for the area by the distance in centimeters that the comb travels through the hair in that run. This distance is read directly from the curve.

It has been our experience, in developing this method, that per cent changes in PCL are similar in value to per cent changes in ACL. For this reason, and

Table I
Combability Results on Bleached Hair
Before and After the Use of a Semipermanent Dye Product
A

Wet Measurements 70°F)
Peak Combing Load (G)

Swatch Number	Before Treatment (BT) Run Number 1	2	3	Average Column	After Treatment (AT) Run Number 1	2	3	Average Column	Per cent Change
1	700.	1050.	1160.	970.	980.	820.	320.	707.	—27.1
2	1500.	1125.	925.	1183.	366.	360.	664.	463.	—60.9
3	525.	690.	1000.	738.	664.	422.	460.	515.	—30.2
4	1200.	1175.	1210.	1195.	650.	900.	616.	722.	—39.6
5	850.	1950.	825.	1208.	436.	500.	480.	472.	—60.9
6	1845.	1425.	1550.	1607.	440.	350.	530.	440.	—72.7

Average BT = 1150, average AT = 553.

$$\text{Per cent change} = \left(\frac{553. - 1150.}{1150.}\right) \times 100 = -52. \text{ per cent.}$$

B

Dry Measurements (65 per cent RH, 70°F)
Peak Combing Load (G)

Swatch Number	Before Treatment Run Number 1	2	3	Column Average	After Treatment Run Number 1	2	3	Average Column	Per cent Change
1	800.	530.	784.	705.	236.	258.	220.	238.	—66.3
2	416.	390.	304.	370.	200.	247.	140.	196.	—47.0
3	500.	340.	275.	372.	263.	198.	140.	200.	—46.2
4	488.	365.	399.	417.	275.	310.	255.	280.	—32.9
5	1180.	800.	500.	827.	400.	210.	370.	327.	—39.5
6	620.	550.	650.	607.	187.	155.	256.	200.	—32.9

Average BT = 550, average AT = 240.

$$\text{Per cent change} = \left(\frac{240. - 550.}{550.}\right) \times 100 = -56 \text{ per cent.}$$

because they are more readily calculated, the use of PCL values is recommended. The computations are best illustrated by considering examples.

Example I

The data, which appears in Table I are typical and correspond to an experiment that was done for the purpose of determining the effect of an experimental semipermanent dye product on the wet and dry combability of bleached hair.

The columns with headings Run 1–3 contain the PCL values for each of the 3 replicate runs that were recorded for each swatch.

The average column consists of the averages of the runs for each swatch. The average before treatment (BT) and average after treatment (AT) values are the averages of the average values appearing in the average columns. The per cent change in PCL is calculated using the expression

$$\frac{(\text{Average PCL AT} - \text{Average PCL BT})}{\text{Average PCL BT}} \times 100 = \text{per cent change in PCL}$$

If average combing loads are measured instead of peak combining loads, the data are treated in an identical manner.

The results of the above set of measurements are summarized as follows. Effect of experimental direct dye base on combability: average per cent change in dry PCL · · · −56. per cent; average per cent change in wet PCL · · · −52. per cent.

The percent change columns on the right hand side of Table I give the per cent changes for the individual swatches. We have chosen not to use these numbers, i.e., their averages, to calculate the total per cent change in PCL, due to the treatment. These numbers, however, give, on inspection, a practical indication of the reproducibility of the experiment and/or treatment effects.

Example II

In most cases, combability measurements involve the comparison of the effects on combability of two or more products. Even when this is not the case, a product whose effect on combability has been previously measured, is normally included in the experiments. This is recommended because it serves as an internal standard which will detect any bias in the results due to differences in the hair. Hair from the same source should always be used in any comparative study.

A comparison between products can be done by measuring the effect on combability of each product individually as in example I and then comparing the average per cent changes. If the effects on combability of two products are sufficiently different, that is, of the order of (per cent change PCL) Product A− (per cent change PCL) Product B $\geqq$ 20 per cent, and if the per cent change in PCL for most of the replicate swatches is uniform, the validity of the observed difference frequently can be decided by simple inspection of the data. If there is any doubt and/or the data are going to be used as part of documentation supporting claims for a product, the statistical significance of the differences must always be established. This is best accomplished by doing an analysis of variance on the data (4). Such an analysis is illustrated as follows with data that were used to compare the effect of shampoo A (Table II) to that of shampoo B (Table III) on the combability of dry human hair. As can be seen in the Tables, 8

Table II

Effect of Shampoo A on the Dry Combability of Untreated Brown Hair

	Peak Combing Load (Grams) 70°F, 65 Per Cent Relative Humidity												
	Before Treatment						After Treatment with Shampoo A						
	Run 1	Run 2	Run 3	Run 4	Run 5	Average Column	Run 1	Run 2	Run 3	Run 4	Run 5	Average Column	Per cent Change
Swatch 1	223.	155.	160.	193.	173.	181.	183.	133.	190.	153.	173.	166.	− 8.
Swatch 2	228.	333.	310.	233.	143.	249.	173.	173.	115.	198.	150.	162.	−35.
Swatch 3	103.	90.	58.	65.	50.	73.	80.	75.	68.	70.	58.	70.	− 4.
Swatch 4	123.	143.	170.	100.	148.	137.	115.	125.	120.	125.	148.	127.	− 7.
Swatch 5	115.	158.	110.	108.	138.	126.	145.	113.	98.	138.	140.	127.	0
Swatch 6	160.	128.	140.	135.	88.	130.	73.	123.	100.	75.	115.	97.	−25.
Swatch 7	90.	170.	125.	193.	213.	158.	123.	138.	100.	253.	93.	141.	−11.
Swatch 8	60.	50.	40.	50.	50.	50.	38.	55.	35.	38.	53.	44.	−12.

Average before treatment = 138.
Average after treatment = 116.8.

$$\text{Per cent change} = \left(\frac{116.8 - 138.}{138.}\right) \times 100 = \mathbf{-15.}\ \text{per cent.}$$

Table III

Effect of Shampoo B on the Dry Combability of Untreated Brown Hair

	Peak Combing Load (Grams) 70°F, 65 Per Cent Relative Humidity												
	Before Treatment						After Treatment with Shampoo B						
	Run 1	Run 2	Run 3	Run 4	Run 5	Average Column	Run 1	Run 2	Run 3	Run 4	Run 5	Average Column	Per cent Change
Swatch 9	138.	113.	178.	143.	150.	144.	255.	110.	195.	93.	213.	173.	+20.
Swatch 10	173.	148.	165.	175.	108.	154.	118.	200.	145.	155.	108.	145.	− 6.
Swatch 11	170.	165.	215.	268.	190.	202.	133.	155.	145.	240.	230.	181.	−10.
Swatch 12	120.	130.	120.	150.	140.	132.	150.	130.	110.	185.	105.	136.	+ 3.
Swatch 13	100.	70.	95.	90.	95.	90.	65.	60.	105.	90.	100.	84.	− 7.
Swatch 14	80.	60.	85.	80.	75.	76.	95.	65.	45.	65.	60.	66.	−13.
Swatch 15	100.	100.	115.	80.	105.	100.	145.	175.	125.	145.	180.	154.	+54.
Swatch 16	110.	80.	65.	85.	100.	88.	60.	55.	60.	45.	65.	57.	−35.

Average before treatment = 123.2.
Average after treatment = 124.5.

$$\text{Per cent change} = \left(\frac{124.5 - 123.2}{123.2}\right) \times 100 = +1 \text{ per cent.}$$

Table IV
Analysis of Variance for Data in Table II

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
Between rows	185,415.7	$n_1 - 1 = 7$	26,488.
Between columns	9,052.5	$n_2 - 1 = 1$	9,052.5
Row X column interaction	14,459.6	$(n_1 - 1) \times (n_2 - 1) = 7$	2,065.7
Residual	73,495.6	$n_1 n_2 (n_3 - 1) = 64$	1,148.4
Total	282,423.4	$n_1 n_2 n_3 - 1 = 73$	

n_1 equals number of rows equals 8 (one for each swatch).
n_2 equals number of columns equals 2 (one for each treatment).
n_3 equals number of replications equals 5 (five for each swatch).

swatches were used and 5 replicate runs were done on each swatch. It can be seen in Table II that the use of shampoo A resulted in a decrease of the forces required to comb 7 out of 8 swatches used. On the other hand, Table III shows that of the 8 swatches that were treated with shampoo B, 3 showed an increase and 5 a decrease in their PCLs.

Analysis of Variance for Data in Table II. The statistical parameters needed to perform the analysis are shown in Table IV. The following operations are done to determine the significance of the different components of variance.

Step 1. Significance of the interaction (between rows and columns) against the residual: 2,065.7/1,148.4 = 1.79. For degrees of freedom (df) $N_1 = 7$, $N_2 = 64$ the above ratio is not significant at the 95 per cent confidence level. (Fisher variance ratio test.) This means that the data do not show any detectable statistically significant interaction between the treatment and the PCLs of the swatches. If the interaction had been significant, it would indicate that the effect of the product is a function of a characteristic of some of the swatches, in our case their initial before treatment average PCL. This seldom occurs if all the swatches are prepared from the same homogeneous batch of hair. If it does, it indicates inhomogeneity of the hair, and the best solution is to prepare more swatches and exclude from the set of swatches those that have extremely high values for their initial before treatment PCL. This should be done on the complete set of swatches participating in the experiment. The set would then be randomly divided in half into subsets to be used with each product.

Step 2. Pooling of the sums of squares of the interaction and residual and their degrees of freedom: (14,459.6 + 73,495.6)/(7 + 64) = 1,238.8. This number is now treated as a new mean square for the residual.

Step 3. Significance of the variance due to differences between columns (i.e., due to shampoo A treatment). The value of the ratio of the mean square of the between columns term and that of the new residual determines the significance of the "between columns" variance: 9,052.5/1,238.8 = 7.31. For degrees of freedom $N_1 = 1$ and $N_2 = 71$ the value of the ratio indicates

Table V
Analysis of Variance for Data in Table III

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
Between rows	133,028.0	$n_1 - 1 = 7$	19,004.0
Between columns	32.5	$n_2 - 1 = 1$	32.5
Row X column interaction	13,401.0	$(n_1 - 1) \times (n_2 - 1) = 7$	1,914.4
Residual	59,972.0	$n_1 n_2 (n_3 - 1) = 64$	937.1
Total	206,433.5	$n_1 n_2 n_3 - 1 = 73$	

n_1 equals number of rows equals 8 (one for each swatch).
n_2 equals number of columns equals 2 (one for each treatment).
n_3 equals number of replications equals 5 (five for each swatch).

statistical significance at the 99 per cent confidence level. This means that the decrease in PCL measured experimentally (−15. per cent) can be considered statistically significant at the 99 per cent confidence level.

Analysis of Variance for the Data in Table III. The parameters needed to perform the analysis appear in Table V.

Step 1. Significance of the interaction: 1,914.4/937.1 = 2.04. For $N_1 = 7$, $N_2 = 64$ the interaction is not significant at the 95 per cent confidence level.

Step 2. Pooling of sums of squares and degrees of freedom: (13,401. + 59,972.)/(7 + 64) = 1,033.4.

Step 3. Significance of the variance due to between columns differences: 32.5/1,033.4 = 0.31. For $N_1 = 1$, $N_2 = 71$ is not significant.

These results confirm that the changes noticed on combing loads (Table III) after the use of shampoo B do not indicate any effect due to this treatment.

The analysis of variance provides us with a criteria to establish the statistical significance of the observed changes in combing forces. In order to compare the effect of shampoo A to that of shampoo B we can proceed as follows.

Step a. Calculate the difference between the average after and average before treatment values for each shampoo, i.e.,

$$\text{average difference for shampoo A} = \overline{D_A} = 116.8 - 138. = -21.2 \text{ g}$$
$$\text{average difference for shampoo B} = \overline{D_B} = 124.5 - 123.2 = 1.3 \text{ g}$$

Step b. Calculate the standard error (standard deviation) of the difference in the means, i.e., D_A and D_B using the formula (5)

$$\text{Standard error} = \frac{\sigma \times \sqrt{2}}{\sqrt{n}} = \sigma_m$$

where σ is the common standard deviation of each of the before and after treatment means, and n (40) is the number of observations used to calculate the means. In our case, σ will be given by the square root of the residual mean square calculated in Step 2 of the analysis of variance. We will have the following:

$$\sigma_{ma} \text{ for shampoo A} = \frac{35.2 \times 1.41}{6.32} = 7.85$$

$$\sigma_{mb} \text{ for shampoo B} = \frac{32.1 \times 1.41}{6.32} = 7.16$$

If desired, these numbers can be used to estimate confidence level limits ($\pm$ L) for the differences, i.e., $\pm L = t \times \sigma_m$. The residual variance used to calculate the standard errors has 74 degrees of freedom. The corresponding value for t for the 95 per cent confidence level is 2.0, hence

$$\pm L_A = \pm 2. \times 7.85 = \mp 15.7 \qquad \pm L_B = \pm 2. \times 7.16 = \pm 14.3$$

and the changes in combing forces for shampoos can be expressed as follows:

Change in PCF shampoo A = -21.2 ± 15.7 g

Change in PCF shampoo B = 1.3 ± 14.3 g

Step c. In order to calculate the significance of the difference between the two average differences for each shampoo we perform a t test. The value for t is given as follows:

$$t = \frac{D_A - D_B}{\sigma_c} \sqrt{\frac{n_1 \times n_2}{n_1 + n_2}}$$

in which σ_c is the combined standard deviation obtained by combining σ_{ma} and σ_{mb}. According to the expression

$$\sigma_c^2 = \frac{\sigma_{ma}^2 \times df_a. + \sigma_{mb}^2 \times df_b}{df_a. + df_b - 2} = 1151.7$$

$$\sigma_C = 33.9$$

where the degrees of freedom = 74. Also, $n_1 = n_2 = 40$. The calculated value of t equals 2.97. The value of t found on a t-table for the 99 per cent confidence level is 2.6. The difference between changes in PCL produced by shampoos A and B is thus shown to be significant at the 99 per cent confidence level.

In the present example, the analysis of variance would have been sufficient to demonstrate the superiority of shampoo A over B, because it showed that shampoo A had a significant effect while shampoo B did not. In other cases, however, if both products are shown to have a significant effect, the calculations under steps a to c leading to the t-test are required in order to prove the superiority of a product over the other one.

Applications

Effect of commercial hair products on combability. Table VI shows the effect of a selection of commercial products on the combability of originally untreated human hair. It can be noticed from the table that most types of hair products, if formulated correctly, can improve the combability of human hair.

Effect of quaternary ammonium compounds on wet combability. The effect of quaternary ammonium compounds on the combability of human hair is well known (6). Figure 5 shows the effect of increasing amounts of dodecyltrimethylammonium chloride sorpted by bleached hair on its combability. The hair was bleached for 60 min using a commercial lightening product. It was then treated by immersing it in 0.05 g/100 g aqueous solutions of the quaternary for 0, 1, 5, 60, and 120 min at room temperature and then rinsing for 20 sec under running deionized water. The amount of quaternary on the hair was determined by extraction with chloroform and further analysis using the method of G. V. Scott (7). Table VII shows similar data for a set of quaternary ammonium compounds (8). The two levels of uptake were pro-

Table VI
Effect of Commercial Hair Products on Combability

Product	Per Cent Change in Peak Combing Force	
	Wet	Dry
Regular shampoo	+ 4.%	− 19.%
Conditioning shampoo A	− 23.%	− 27.%
Conditioning shampoo B	− 57.%	+ 31.%
Leave-in creme rinse	− 40.%	− 72.%
Rinse-off creme rinse	− 69.%	− 48.%
Semipermanent dye product	− 38.%	− 34.%
Oxidation dye product A	− 55.%	− 15.%
Oxidation dye product B	+741.%	+ 47.%
Oxidation dye product B plus a rinse-off creme rinse	− 65.%	− 25.%
Lightener (15-min treatment)	+265.%	+ 20.%
Lightener (60-min treatment)	+760.%	+110.%
Lightener (60-min treatment) plus a conditioner	+180.%	− 20.%
Conditioning setting lotion	− 63.%	− 72.%

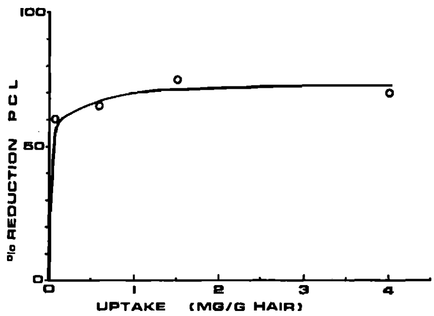

Figure 5. Per cent reduction in wet PCL as function of uptake of dodecyltrimethylammonium chloride on bleached hair

duced by immersing the bleached hair in 1.0 and .05 g/100 g aqueous solutions of the quaternaries for 5 min at room temperature and then rinsing 20 sec as was previously done.

The data showed that only very small amounts of these compounds are needed on the hair in order to produce significant effects on combability, and that increasing the uptake beyond these values does not result in additional benefits. It should be kept in mind that the uptake of these compounds by hair is going to be affected by the pH of the medium, the presence of other compounds in solution (especially anionics), and the type of hair.

Table VII
Effect of Uptake of Quarternary Ammonium Compounds on the Combability of Wet Bleached Hair

	1.0 g/100 g solution 5 min		.05 g/100 g solution 5 min	
Compound	Uptake mg/g Hair	Per cent reduction in PCF	Uptake mg/g Hair	Per cent reduction in PCF
Tetradecyltrimethylammonium chloride	5.9	94. per cent	.2	92. per cent
Decyltrimethylammonium chloride	9.0	83. per cent	1.5	78. per cent
Stearyl dimethylbenzylammonium chloride	2.5	90. per cent	.8	90. per cent
Benzyltrimethylammonium chloride	4.0	54. per cent	.25	50. per cent
Distearyl dimethylammonium chloride	3.6	92. per cent	.2	92. per cent

Discussion

In principle, combability measurements are very simple. In practice, unless great care is taken in the preparation treatment, handling of the swatches, and statistical analysis of the data, the results can lose significance. This is especially true when establishing small differences between products. The main problem arises from the fact that it is difficult to produce a reproducible degree of tangling of the swatches prior to the measurements. In our experience, if the method is followed carefully, changes in combability of the order of ± 20 per cent can be accurately established without having to measure an impractically large number of swatches. Changes of this order appear to be close to the lower limit of what can be subjectively noticed by combing swatches by hand.

In this method, the before treatment measurements are done on hair which has been cleaned using a detergent solution. This is perfectly justified in testing most products because, in reality, shampooing usually precedes the use of most hair care preparations. In the cases where the effects of shampoos are being measured, it could be argued that the starting point should be unclean hair which, in many cases, has better combability than clean hair. This approach, however, will introduce the unnecessary complication of having to arbitrarily define and reproducibly simulate dirty hair in the laboratory. Although this could be done, we consider that it is justified to start with clean hair and define any effect that a shampoo can have on combability as those effects that can be measured in addition, and beyond the effect produced by shampoos by virtue of just cleaning the hair.

In our method, we chose to quantify combability in terms of PCL and ACL. In particular, PCLs are relevant in terms of what is experienced subjectively while combing hair. This is not only because they correspond to the highest forces, but also because, as shown by the combing curves, they occur abruptly. This characteristic of combing forces has been used by Wedderburn and Prall (3) as the basis for developing a method for measuring combability. It is likely, as pointed out by these authors, that fast short-term fluctuations in the combing forces, i.e., "tangle noise" or "raspiness" (2), are a factor contributing to the subjective perception of combing resistance. The inclusion of this effect in the evaluation of combability would be most critical in cases where the effect of two products which produce combing curves of similar PCL, but dissimilar "raspiness" were being compared. This situation, however, has not yet arisen in our experience, and we find that qualitatively PCLs increase or decrease simultaneously with the noise level in the combing curves, i.e., smooth curves give small PCLs, while scratchy curves give large ones. Short-term variations in combing forces thus appear to give similar information to that given by PCL. In the absence of a detailed description of the Wedderburn-Prall method, it is not presently possible to do a fair comparison with ours. The method developed by Newman *et al.* (1) is similar to ours. It involves the insertion of a comb into a swatch of hair and the measurement of the forces opposing its motion. The authors indicate that after less than a second of comb motion at a rate of 1.5 mm/sec, the combing force reaches a nearly constant value, which is measured. This contrasts sharply with the shape of our combing curves (Figs. 1 and 2), and indicates that these measurements are being done on hair swatches that, either because of their size and geometry and/or because of the way in which they are handled prior to the measurements, do not get tangled before and/or while they are being combed. This approach, although desirable from the point of view of improving reproducibility, is not favored by us, because in reality, tangles are almost always encountered while combing hair, and detangling is an integral part of the function of products developed to improve the combability of hair.

Combability measurements have been reported to be in use at Hoffman-LaRoche Co. Laboratory, but the method has not been described in detail. The method developed by Waggoner and Scott (2), which involves the measurement and analysis of the sound frequencies generated when hair is combed, although it is an interesting approach, suffers in our opinion from the unnecessary complications introduced by the necessity of having to interpret the generation of sound in terms of combing frictional forces which can more easily and directly be measured in the first place.

Conclusion

The increasingly sophisticated product development taking place in our industry is in need of methods which can objectively measure the effect of products on human hair. Although these methods do not completely replace the subjective evaluation of a product's performance, they are obviously of great help in guiding research and in substantiating performance claims made for hair products. Furthermore, by providing quantitative data these methods open the door to the investigation of the underlying physico-chemical phenomena involved in the modification of human hair for cosmetic purposes.

The combability method described in this paper has proven very useful in our laboratory. The authors hope that others will benefit from its use.

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