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Hair breakage during combing. III. The effects of bleaching and conditioning on short and long segment breakage by wet and dry combing of tresses

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Synopsis

A recent publication (1), provided evidence for two types of hair breakage during combing, short segment breakage (approximately less than 1.27 cm) and longer segment breakage. We have confirmed these results and refined the separation distance between short and long segment breakage at about 2.54 cm. Furthermore, chemical bleaching increased both short and long segment breakage while a commercial hair conditioner decreased both types of breakage.

Whether the hair is chemically bleached or conditioned, for dry combing, short segment breakage increases with increasing comb strokes, that is, short segment breakage increases as combing damages the ends of the hair, however, long segment breakage does not increase with increasing comb strokes. Wet combing provided a decrease in short segment breakage and an increase in long segment breaks, but no increase in breakage with increasing comb strokes.

Mechanical combing of tresses shows similar results qualitatively, however the variance was too large and adjustments need to be made to provide for a larger number of broken hairs to bring the mechanical and hand combing results in line.

For dry combing, as the comb descends through the hair, hairs above it are made parallel and those beneath are either made parallel or knot by, hairs looping around other hairs or hairs looping around comb teeth and other hairs several cm between the comb and the hair tips. As the comb advances through the looped/knotted hairs long breaks occur or as the comb descends near the tips wrapped ends can result. End wrapping by inertia & possibly static charge produces short segment breaks which are more severe if the hair is cut at 90 degrees versus a tapered cut.

For wet combing, clumping of hairs by a capillary action produces fewer short segment breaks, by reducing end wrapping; however, crossed hair interactions occur & because of higher friction more severe snags arise higher up in the tress, and lower hair breaking load due to plasticization by water, producing a larger number of long segment breaks.

The very best practical way to evaluate hair strength is by counting the actual number of short and long segment breaks and by considering both wet and dry combing.

INTRODUCTION

In a previous paper (1), it was demonstrated that during hand combing of hair, short fiber fragmentation (less than about 1.27 cm) and longer segment breakage occurs by different pathways. It was proposed that longer segment breaks occur primarily by

impact loading of one hair fiber over another which causes breakage at loads lower than tensile break loads, and breakage occurs at the hair-to-hair contact point with essentially no increase in hair length (strain) versus normal tensile loading which produces large strain increases (1,2). But, short segment breakage involves the wrapping of distal ends of hairs around comb teeth as shown by (1,2), thus increasing the end-peak force and with continued combing the ends are damaged more and more ultimately producing an increasing number of short segment breaks.

The purpose of this current investigation was to re-examine the cut-off between short and long segment breakage, to investigate the effects of bleaching and conditioning on short and long segment breakage by both hand combing and by mechanical combing of hair tresses, to compare wet and dry combing effects and to develop a better understanding of how hair snags form during combing.

EXPERIMENTAL

TRESS MAKING AND PREPARATION

Tresses were made using six grams of 12 inch dark brown Italian hair from DeMeo Brothers, New York, NY for hand combing over the bottom 6 inches (~15 cm) of the tresses. To produce approximately the same comb stroke distance over the same portion of hair in mechanical combing, 5 grams of 9.75 inch (25 cm), (2.25 inches (5.7 cm) was cut off from the root end of this same 12 inch (30.5 cm) hair tress) dark brown Italian hair was used for making tresses.

The tresses were washed with a commercial cleaning shampoo based on sodium laureth sulfate and then dried and carefully detangled both wet and dry using a wide toothed comb. For both mechanical combing and hand combing, some of these tresses were bleached for 45 minutes with product from a commercial bleaching kit containing a peroxide persulfate mixture and then the bleaching agent was carefully rinsed out and the tresses hung up to dry. These bleached tresses were carefully detangled and washed again with the commercial cleaning shampoo and some of these tresses were air dried after detangling and others treated with a commercial hair conditioner, rinsed with tap water, detangled and hung up to dry overnight.

HAND COMBING

Dry hand combing was at 60 ± 2% RH and room temperature. Prior to combing for collecting hair fragments, the tresses were carefully detangled (10 comb strokes) with a wide tooth comb. The tresses were then combed 25 comb strokes at a rapid comb stroke rate using the fine tooth part of an ACE all purpose comb (#61286) starting each comb stroke at approximately six inches (15 cm) from the tip end of the tress and the broken hair fragments were collected on a large 18 × 24 inch (46 × 61 cm) piece of white poster board and separated by size into groups of less than 1 inch (2.54 cm) length, 1 inch to 2.5 inches (2.5 to 6.4 cm), 2.5 to 5 inches (6.4 to 12.7 cm) and longer than 5 inch lengths (12.7 cm) and the hair fragments in each group counted. Separate combs were used to avoid transfer of conditioner or surface ingredients between tresses. The tresses were combed a 2^{nd}, 3^{rd} and 4^{th} time at 25 comb strokes each for a total of 100 comb

strokes per tress and the fragments collected by size and counted. The data was analyzed statistically by a modeling program from Statistical Analysis Systems (3).

A similar procedure was followed for wet combing with the following changes. Each tress was washed with the commercial cleaning shampoo on the previous day and detangled with a comb when wet. The following day one tress was wet with water under the tap and placed in 125 ml of tap water (American Water Co.) in a 250 ml beaker for 2 minutes and then the water squeezed out between the forefinger and thumb into the beaker and the tress combed 10 comb strokes starting the combing at the mid-point of the tress. Broken hairs were removed from the tress onto an 18 × 24 inch piece of white fiber board and then the tress was combed another 15 comb strokes and all hair fragments carefully removed from the comb and then the tress was dipped into the beaker with water and swirled and water and hair removed by squeezing with the fingers 3 times to remove small broken hair clinging to the hair tress. The beaker was allowed to stand for at least 3 minutes, then the small hairs generally less than 0.64 cm (1/4 inch) were counted in the beaker. Hairs were separated by size <0.64, <1.27, <2.54, <6.35, <12.7 cm and counted. Each tress was combed a 2nd 3rd and 4th time, as above separating and counting the hairs by size in the same manner. The data from all combing experiments was analyzed statistically by a modeling program from Statistical Analysis Systems (3).

MECHANICAL COMBING

The tresses were detangled carefully using a wide tooth comb (separate combs used to avoid transfer of conditioner or surface ingredients between tresses) and stored prior to mechanical combing.

The tresses were combed (at 60 to 65% RH and room temperature) at a comb stroke rate of 80/min for 1000 or 2000 comb strokes using the fine toothed portion of an ACE all purpose comb [(#61286) (same as for hand combing using separate combs per tress)] and the broken hair fragments were collected and saved for counting. The data was analyzed statistically by a modeling program from Statistical Analysis Systems (3).

RESULTS AND DISCUSSION

HAND COMBING

The data of Table I confirms the conclusions from the earlier study showing more short segment hair fragments (<2.54 cm) than long segment fragments (>2.54 cm) and an increase in short segment breakage with increasing comb strokes (1). These data versus the previous data also show a better cut-off between long and short segment breakage at 2.54 cm (1).

An increase in short segment breakage occurs with increasing combing damage near the ends of the hair fibers resulting in an increase in the number of short segment breaks, but a similar effect does not occur for long segment breakage, that is the number of long segment breaks does not increase with an increasing number of comb strokes.

This effect confirms the previous finding and suggests a different mechanism for long versus short segment breakage as suggested in the previous publication (1). Short

Table I
Long versus Short Segment Breakage and Hair Length*

	Number of broken hairs at length (cm) (average of 3 replicas)			
No. of comb strokes	<2.54	2.54–6.4	6.4–12.7	>12.7
25	28	4	1	1
50	44.3	4.7	1	1
75	45.7	3.7	1.3	1.3
100	68.7	5.3	0.3	2

* Dry combing at 60 ± 2% RH.
Significant difference in breakage by lengths, $p = 0.0001$.
No. of short segment breaks increase with no. of comb strokes ($p = 0.001$). No. of long segment breaks do not change with no. of comb strokes ($p = 0.29$).

segment breakage most likely occurs primarily by end wrapping and subsequent damage to the ends of the fibers by abrasion and deformation and ultimately breakage occurs primarily by deformation when the ends are sufficiently weakened. The wrapping of distal ends of hairs around comb teeth (1,2), increases the end-peak force and with continued combing the ends are damaged more and more, producing fiber/fiber entanglements, and consequently an increase in the number of short segment breaks. The wrapping of hair ends around comb teeth during combing most likely is driven by inertia in which the motion of the comb through the hair near the tip, especially where the hair has a slight curl at the end, produces a tendency for hair fibers to move and curl around the comb teeth (1,2). Since more numerous short segment breaks occurs in the dry than wet state, static charge may also be involved in end wrapping. This end breakage effect is consistent with an effect found by Garcial *et al.* (4) who studied cuticle wear patterns among 6 Caucasian subjects who had never chemically treated their hair in which their hair ranged from 30 to 60 cm long. These scientists found that hairs 30 cm long on the scalp had lost many more cuticle cell layers at the distal ends than 60 cm hair at a distance of 30 cm from the scalp. They concluded that "at any common distance from the scalp x, the preservation of the cuticle is better for a longer hair subject", because of greater wear and breakage at the ends. The "distal-end-scale-loss" effect observed by these scientists is most likely due to the end wrapping effect described above.

As described earlier (1), long segment breakage most likely involves impact loading of one hair fiber against another and is dependent on the probability that taut crossover hairs occur in snags and one hair impacts over another as the comb breaks through or detangles the snag.

The data summarized in Table II shows the effects of hair bleaching on short (<2.54 cm) and long segment (>2.54 cm) breakage when hand combing Caucasian hair dry. The hair was bleached with a peroxide-persulfate commercial bleaching product as described in the Experimental section. These data show a significant increase in both long and short segment breakage by bleaching and significantly more short versus long segment breakage. For the short segment breakage, chemical bleaching increases interfiber friction and makes the ends more susceptible to damage by combing. Therefore, bleaching increases short segment breakage which also increases with the number of comb strokes. For the long segment breakage (Table III), bleaching increases inter-fiber friction thereby in-

Table II
Long versus Short Segment Breakage and Number of Comb Strokes*

	Number of broken hairs at length (cm) (average of 3 replicas)							
	Non-bleached hair				Bleached hair			
No. of strokes	<2.54	2.54–6.4	6.4–12.7	>12.7	<2.54	2.54–6.4	6.4–12.7	>12.7
12	28	4	1	1	50.3	12	5	3
50	44.3	4.7	1	1	67.7	11.3	4.7	4.3
75	45.7	3.7	1.3	1.3	98.7	22.3	8	3
100	68.7	5.3	0.3	2	111.3	22.3	3.7	2.3

* Dry combing at 60% relative humidity.
Significant bleaching effect, $p = 0.0001$.
Significant short (<2.54 cm) vs long segment breakage, $p = 0.0001$. Significant comb stroke effect for short segments, $p = 0.0002$. No significant comb stroke effect for long segments, $p = 0.47$.

Table III
Bleaching Then Conditioner and Long versus Short Fragment Breakage*

	Number of broken hairs at length (cm) (average of 3 replicas)							
	Bleaching + conditioner				Bleached hair			
No. of strokes	<2.54	2.54–6.4	6.4–12.7	>12.7	<2.54	2.54–6.4	6.4–12.7	>12.7
25	22.3	3	0.7	1.3	50.3	12	5	3
50	25	4	0.7	0.7	67.7	11.3	4.7	4.3
75	26.7	1.3	0.3	0.7	98.7	22.3	8	3
100	38.7	4.3	1.3	1.3	111.3	22	3.7	2.3

* Dry combing of hair at 60 ± 2% RH.
Significant conditioner effect, $p = 0.0001$.
Significant short vs long segment effect, $p = 0.0001$. Significant comb stroke effect only for short segments, $p = 0.0025$. No significant comb stroke effect for long segments, $p = 0.35$.

creasing snag formation providing more crossover hairs higher up in the tress for hair-on-hair impacting and in that manner long segment breakage increases. However, since bleaching does not show an increase in long segment breakage with an increasing number of comb strokes, the damage by combing per se does not accentuate nor does it contribute to long segment hair breakage of bleached hair.

The experiment summarized by Table III was run to test the effects of hair conditioning on short and long segment breakage by dry combing. Chemically bleached hair was used and it was treated with one of the leading hair conditioners currently sold in the marketplace. These data show a significant reduction in both short (<2.54 cm) and long segment (>2.54 cm) breakage by this conditioner. There is also a significant comb stroke effect, but, as is the case for shampooed non-chemically treated hair and for bleached hair washed with a cleaning shampoo, it is only significant for short segment breakage and not for long segment breakage.

Conditioners function primarily by reducing inter-fiber friction and thereby they reduce the number and severity of entanglements that result in those crossover hair fiber arrangements necessary for impact loading in long segment breakage (1,2). Furthermore,

conditioners reduce end wrapping and the abrasive damage that occurs to the fiber-ends and in that manner they produce a decrease in short segment breakage.

MECHANICAL COMBING

Mechanical combing of hair produced unexpected results. We tried to simulate the conditions for hand combing by using the same size hair tresses and the same length of comb stroke as for hand combing. This was a mistake, because as the results show, the hand combing was obviously more vigorous, probably in part due to thumb pressure on the hair to hold it snugly in the comb during hand combing and most likely a faster comb stroke. This hand combing technique was developed to maximize reproducibility rather than to mimic combing hair on the head, however, the comber and technique were tested during the late 1980's and 1990's in a series of consumer tests in Asia, Europe and Latin America where a range of conditioning products were tested for combability/conditioning and the consumer response was in complete agreement with the combing results.

The data of Table IV show that for many more comb strokes there were fewer broken hair fragments by mechanical combing than by hand combing. Even though the results show similar effects numerically, because of the large variance for mechanical combing the data of Table 4 are not statistically significant. We intend to repeat these results after making adjustments to the mechanical combing to produce a larger number of broken hairs.

WET VERSUS DRY COMBING AND BREAKAGE

Wet combing produced interesting and contrasting results compared to dry combing. For example, a larger number of long segment breaks and fewer short segment breaks were produced by wet combing, see the data of Table V. For wet combing, clumping of hairs was readily observed and the tip ends of the fibers were not as free to produce end wrapping. This clumping occurs by a capillary action producing fewer short segment breaks; however, crossed hair interactions occur higher up in the tress & because of higher friction more severe snags arise higher up in the tress than in dry combing, producing a larger number of long segment breaks. This snagging higher up in the tress was also readily observed during combing.

Table IV
Mechanical Combing of Hair Tresses*

Number of broken hairs at length (cm) (average of 4 replicas)						
	Non-bleaching+shampoo		Bleach+shampoo		Bleach+conditioner	
No. of strokes	<2.54	>2.54	<2.54	>2.54	<2.54	>2.54
1000	25.3	0	43.5	13.3	19.8	2
2000	25	0	44.3	6	20	0

* Dry combing of hair at 65% RH.
No significant treatment effect, p = 0.62. Significant short vs long segment breakage, p = 0.001. No significant comb stroke effect, p = 0.66.

Table V
Wet Versus Dry Combing of Hair

Number of broken hairs at length (cm) (average of 3 replicas)				
	Wet combing data		Dry combing data	
No. of strokes	<2.54	>2.54	<2.54	>2.54
25	16.7	22.7	28	6
50	25.7	19.7	44.3	6.7
75	22.7	23.7	45.7	6.3
100	23.7	24.3	68.7	5.8

Short segments only, wet vs dry is significant, $p < 0.0001$.
Long segments only, wet vs dry is significant, $p < 0.0001$.
No significant comb stroke effect for wet short or long segments.

HOW HAIR FIBERS FORM SNAGS AND THE INFLUENCE ON BREAKAGE

Prior to combing, hairs exist in complex interwoven patterns. For dry combing, as the comb descends through the hair, hairs above it are made parallel and those beneath the comb are either made parallel or knotted by, hairs looping around other hairs (5), or hairs looping around comb teeth and other hairs (1) several cm between the comb and the distal tips of the hair. As the comb advances through the looped/knotted hairs long breaks can occur or as the comb descends near the tips wrapped ends (1) can result. End wrapping by inertia & possibly static charge produces short segment breaks which are more numerous if the hair is cut at 90 degrees versus a tapered cut.

For wet combing, clumping of hairs by a capillary action produces fewer short segment breaks, by reducing end wrapping; however, crossed hair interactions occur higher up in the tress and because of higher friction produces more severe snags higher up in the tress resulting in a larger number of long segment breaks.

SUMMARY AND CONCLUSIONS

A recent publication (1), provided evidence for two types of hair breakage during combing, short segment breakage (approximately less than 1.27 cm) and longer segment breakage. We have confirmed these results and refined the separation distance between short and long segment breakage at about 2.54 cm. Furthermore, chemical bleaching increased both short and long segment breakage while a commercial hair conditioner decreased both types of breakage.

Whether the hair is chemically bleached or conditioned, short segment breakage increases with increasing comb strokes, that is, short segment breakage increases as combing damages the ends of the hair, however, long segment breakage does not increase with increasing comb strokes. For wet combing, clumping of hairs by a capillary action produces fewer short segment breaks, by reducing end wrapping; however, snags form higher up in the tress because of higher friction producing a larger number of long segment breaks.

Mechanical combing of tresses shows similar qualitative results, however the variance

was too large and adjustments need to be made to provide for a larger number of broken hairs to continue the hand versus mechanical combing comparison.

For dry combing, as the comb advances through looped/knotted hairs long breaks can occur or as the comb descends wrapped ends can result near the tips. End wrapping by inertia and possibly static charge produces short segment breaks which are more numerous if the hair is cut at 90 degrees (large number of tip ends in a narrow region of tress at the tip end) versus a tapered cut.

The very best practical way to evaluate hair strength is by counting the actual number of short and long segment breaks and by considering both wet and dry combing.

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REFERENCES

(1) C. Robbins, Hair breakage during combing. II. Impact loading and hair breakage, *J. Cosmet. Sci.* **57,** 245–257 (2006).
(2) C. Robbins, Hair breakage during combing. I. Pathways of breakage, *J. Cosmet. Sci.* **57,** 233–243 (2006).
(3) Statistical analysis was by a modeling program from JMP 5.1 by Statistical Analysis Systems (SAS, Campus Drive, Cary, NC 27513).
(4) M. L. Garcia, J. A. Epps, and R. S. Yare, Normal cuticle-wear patterns in human hair, *J. Soc. Cosmet. Chem.* **29,** 155–177 (1978).
(5) A. C. Brown and J. A. Swift, The mechanics of fracture of human hair, *J. Soc. Cosmetic Chem.,* **26,** 289–299 (1975).