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Hair breakage by combing and brushing—A comment on: *T. A. Evans and K. Park, A statistical analysis of hair breakage. II. Repeated grooming experiments, J. Cosmet. Sci., 41, 439–456 (2010)*

Y. K. KAMATH and C. ROBBINS, *Kamath Consulting Inc., 11 Deer Park Drive, Monmouth Junction, NJ 08852 (Y.K.K.), and 12425 Lake Ridge Circle, Clermont, FL 34711 (C.R.).*

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Synopsis

Literature dealing with the mechanisms of hair breakage in combing and brushing published so far has been reviewed as a background for the critical evaluation of the method and data analysis of the paper "Statistical Analysis of Hair Breakage. II" by Evans and Park (1). Accumulated knowledge about hair breakage in these grooming processes indicates that hair breakage in combing and brushing results from tangling, looping, knotting, and impact loading. Fatiguing, though responsible for some weakening of the fiber in the grooming process, it is unlikely to be a significant factor in hair breakage in combing and brushing.

INTRODUCTION

Hair breakage is a complex multifactorial phenomenon involving:

- Tangle formation with hair fibers looped over other hairs and severe bending deformations (2)
- Impact breakage (3) or pulling a comb or brush through a tangle with breakage
- Knots (4) that form more with high curvature and are easily fractured
- Treatments and weathering (5–10): Chemical damage increases breakage and conditioners decrease breakage
- Relative humidity or water content of the hair (10,11): Highly coiled hair breaks more by dry state grooming (10) while straight-to-wavy hair provides more short segment breaks (< 2.5 cm) when dry (10), but more long segment breaks when wet (10)
- Physical damage or wear by abrasion (1,3,10,12) from specific grooming devices such as combs, picks or brushes, and to some extent a fatiguing action

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DISCUSSION

TANGLE FORMATION INVOLVING HAIR FIBERS LOOPED OVER OTHER HAIRS AND SEVERE BENDING DEFORMATIONS

The number and complexity of tangles increase with hair fiber curvature (10,11), producing higher combing forces as shown by Epps and Wolfram (11) in the midlength and end peak regions of combing force curves. Even with relatively straight-to-wavy hair, in dry combing, tangles form near the tip ends from end wrapping, leading to a higher end peak force with a relatively low midlength force as shown by Kamath and Weigmann (13). Brown and Swift (2) examined the combing of Caucasian hair tresses in the scanning electron microscope (SEM) and observed that severe bending deformations in hair tangles are involved in hair breakage. They observed further that "the tangle tightened to the extent that a few individual hairs began to break and this occurred predominantly at a loop." Since this type of break occurred frequently, they examined hair fiber loops near the root end and tip end of the fibers and noted two types of loop breakage. One type of loop involved pulling both ends of a hair fiber so that virtually no slippage occurred. Near the root end they observed smooth fractures, but as the site of the loop moved down toward the tip they observed more longitudinal splitting or step fractures until fibrillation occurred near the tip end. With another type of loop, they attached one end and pulled on the other end, which resulted in the hair moving slowly as it tightened over the wire. In this case they always observed longitudinal splitting due to high stresses building at the crack tip having a strong tendency to diverge in the axial direction. Robbins (3) observed similar effects by looping hair fibers over other hairs and fracturing by impact loading.

IMPACT BREAKAGE OR PULLING A COMB OR BRUSH THROUGH A TANGLE WITH BREAKAGE

Impact loading involves tangle formation and the grooming force to brush through a tangle. It has been demonstrated that hair fibers can be broken more easily by impact with virtually no increase in length (as in tensile loading) and that hair fibers break more readily by impact loading than by tensile extension (3). Therefore, hairs can be broken by impact (3), which involves rapidly pulling a brush or a comb through a tangle where one or more hairs are looped over another hair or by pulling through a difficult snag of looped hair (2). Whether or not it is necessary for the fiber to be previously weakened by wear or by fatiguing may be determined by the type of fracture because Kamath and Weigmann (13) have described different types of hair fractures, specifying some conditions, and Robbins *et al*. (14) have described in more detail conditions that produce different types of hair fractures. Furthermore, some hair fibers broken in tress combing experiments have been shown to provide smooth breaks (3) indicative of minimum prior damage (13,14) from wear or fatiguing.

KNOTS FORM IN HIGH CURVATURE HAIR AND ARE EASILY FRACTURED

Knot formation is also related to fiber curvature, being highest in African-type hair (4). Khumalo *et al.* (4) demonstrated that more broken hairs are formed on African hair by

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consumers using their own combing devices than by Caucasians or Asians. Furthermore, these scientists found 13% of the fibers from two African subjects had knots that they concluded lead to hair breakage. Robbins (3) later demonstrated that hair fibers with knots break under impact more easily than hair fibers without knots and that when breakage occurs it is at the knot. The conclusion is that breakage occurs at knots because of severe bending deformations analogous to severe bending at fiber loops in tangles as suggested by Brown and Swift (2), causing the fibers to break more easily by impact or by breaking through the tangle.

Apart from knot formation, in very curly hair with high ellipticity torsional deformation can make a significant contribution to hair breakage, because such fibers have suffered significant damage during normal daily grooming in the regions of twist. These regions are further stressed by the torsional deformations that occur when the hair passes through the teeth of the comb. These fibers can fail by a combination of torsional stresses working in tandem with relatively low tensile loads. Such effects are unlikely to be of much importance in the case of fibers that are straight or have only a slight curvature.

TREATMENTS AND WEATHERING: CHEMICAL DAMAGE INCREASES BREAKAGE AND CONDITIONERS DECREASE BREAKAGE

Chemical damage by perms (5), bleaches (6), permanent dyes (7), straighteners (8), and sunlight exposure (9) weaken hair and increase interfiber friction and abrasive damage, leading to more tangle formation and to more hair breakage. Straighteners do decrease curvature and in that manner decrease tangles, but they often weaken hair to the extent that they make the hair brittle. On the other hand, surface treatments such as conditioners, which make hair combing and brushing easier, have been shown to produce less breakage (10).

RELATIVE HUMIDITY OR WATER CONTENT OF THE HAIR

Relative humidity or the amount of water in the fibers can also affect hair combing forces and hair breakage (10). Epps and Wolfram (11) demonstrated that the work of combing highly coiled African hair is lower when the hair is wet than when it is dry, while the reverse holds for wavy-to-straight Caucasians hair (10,11). But this is true for all highly coiled hair versus straight-to-wavy hair (15). For example, highly coiled hair, such as from a permanent wave or highly coiled African, Caucasian, or even Asian hair, provides significantly higher combing (11,15) or brushing forces in the dry state than in the wet state and more dry-state than wet-state breakage. This effect occurs because water breaks some of the hydrogen bonds and salt linkages, resulting in relaxation of the curl, which reduces tangles.

On the other hand, straight-to-wavy Caucasian or Asian hair produces higher midlength combing forces in the wet rather than the dry state (3), but a higher end peak force at moderate-to-low relative humidity, explaining why this type of hair provides more long-segment breaks when wet (9), but more short segment breaks when dry (10). Therefore, when we consider the total number of grooming strokes during the day, we must consider three states of relative humidity. The first state considers the number of grooming strokes

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in the wet state; if one blow dries the hair, we must consider the transition from the wet to the dry state and the number of grooming strokes, and finally we must consider the number of grooming strokes in the dry state. Therefore, to simply assign a number of grooming strokes per day without considering the state of the water content and the hair type is too simplistic.

PHYSICAL DAMAGE OR WEAR BY ABRASION FROM SPECIFIC GROOMING DEVICES SUCH AS COMBS, PICKS, OR BRUSHES, AND FATIGUING OR PULLING THROUGH A TANGLE WITHOUT BREAKAGE

Wear by abrasion occurs over the entire fiber but more near the fiber tip end because of a longer residence time, but even more so by high end peak forces when dry (3), as evidenced by examination of many of the smaller fragments of short segment breaks (3,10). Combs or brushes with more space between the teeth or bristles can lead to fewer and less complex tangles and therefore to lower combing forces, less abrasion, less fatiguing, and fewer broken hairs; some brushes provide more long segment breaks and fewer short segment breaks than combs (18).

Fatiguing occurs primarily between the root section of the fiber and the brush or comb where the combing device encounters a snag, but only on the fibers that are under tension at the snag, which generally is a very low percentage of the fibers in the area being combed or in the brush. Therefore, fatiguing and impacting are related, but impact breakage is produced by a single impact; however, fatiguing can produce breakage only by hundreds to thousands of impacts over the same section of the same fiber. Therefore, for the same section of the same fiber to be impacted sufficiently thousands of times and each time to cause fatigue damage is a much lower probability occurrence than for a single hair under high tension to be impacted once and broken.

The recent paper by Evans and Park (1) on hair breakage suggests that fatiguing is the primary reason for hair breakage and raises some important questions about hair breakage. Evans and Park used the combing wheel to brush hair repeatedly at a certain frequency, at 60% RH only, and collected the broken fibers as a function of the number of brushing strokes up to 10,000 strokes. In Figure 4 of their paper, as expected of a good conditioner, we see a nearly 60% reduction in breakage. Then they proceeded to apply Weibull statistics to hair breakage data in Table I, assuming that combing or brushing amounts to fatiguing hair, eventually leading to catastrophic failure.

It is true that in the past a significant amount of work has been done on the mechanisms of the weakening of fibers by fatiguing and the mechanism of protection of hair fibers by conditioners using Weibull statistics (18). However, whether this approach can be used to interpret hair breakage in combing or brushing is questionable. The authors calculated the shape parameter and the characteristic life for virgin and bleached damaged hair, and for hair treated with conditioners. The definition of the characteristic life for hair breakage is the number of brushing strokes necessary for breaking 63.2% of the fibers. For virgin hair, the characteristic life is given as 55.2 million brush strokes, and for the same hair after conditioning it increases to 1.04 billion brush strokes. But the data for these huge numbers are based on only 10,000 brush strokes and only 1.6% of the fibers broken (326 of 20,000) as compared to 12,640 fibers corresponding to the definition of characteristic life.

These characteristic life values are so large relative to the actual data that they are of questionable reliability. For example, assuming brushing at the rate of 1 stroke/s (the authors

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have used 50 strokes/min), the two numbers correspond to 1.72 and 33 years, respectively, of continuous brushing to break 63.2% of the fibers. Evans and Park (1) do admit, "Specifically, a prediction involving the outcome after tens of millions of cycles based on an experiment involving a few thousand cycles, is obviously dubious." Nevertheless, they continue by saying "that together these two Weibull parameters describe the collected data," and they proceed to calculate predicted probabilities for hair breakage with a "reasonable representation of real life conditions." Furthermore, they suggest that longer fragment breaks can be "explained in terms of the gradual brushing out of snags and tangles," which, because of the questionable characteristic life, may or may not have anything to do with the fatiguing process.

The concept of pooling the data, which the authors adopted, though good for typical fiber fatigue experiments conducted under precise conditions, is not desirable for a brushing or combing experiment for predicting hair breakage on heads because brushing 2500 fibers in eight different experiments is not the same as brushing 20,000 fibers in one experiment. This is also true of calculating failure probabilities on actual heads, based on the data collected by combing tresses containing 2500 hairs.

Fatigue data are extremely sensitive to applied stress concentrations (1). The applied stress should be high enough to break a significant fraction (~30–50%) of the test specimens. The brushing experiment described in this paper (or similar combing experiment) does not meet these criteria. The nature of the brushing force curve shows that the stress on the fibers during the midlength traverse of the brush, the region where long segment breaks occur, is very low for the vast majority of the fibers (because it is shared unequally by 2500 fibers). Even the end peak force, which is higher than the midlength force, is likely to stress only a very few fibers to significant levels to cause significant damage because the force per fiber is likely to be very small and uneven.

A brushing force curve for a tress will provide some idea of the stress levels in these experiments, and considering the large number of fibers, they are likely to be very small. Therefore, the fracture mechanism based on flaw propagation by fatiguing in real brushing and combing situations, which requires hundreds to thousands of high-stress fatiguing actions on the same region of the same fiber, may occur with a few fibers, but it is not the primary cause of hair breakage, especially for long segment breaks.

The authors state correctly that in the studies on hair breakage by Robbins and Kamath (3–6) we focused heavily on the size of the broken hair fragments and that we related the effects primarily to fiber looping and entanglements and thus to high localized stresses on a few fibers rather than lower localized stresses on exactly the same regions on the same fibers. But, Evans and Park then state an alternative mechanism (1): "In short, there is another breakage mechanism that involves progressive propagation of flaws within the fiber, and it does not require the presence and occurrence of tangles." We cannot conceive of combing or brushing a full head of eight-inch or longer hair without any tangles. We believe that increasing long segment breaks with increasing curvature by the creation of flaws by fatiguing only cannot explain hair breakage on live heads, and one cannot ignore direct breakage by fiber looping and tangling with severe bending stresses that produce breakage by either impact or pulling the comb or brush through the tangle (1,10). This is especially true in a mechanical brushing process used by the authors, where the brush traverses the tress at relatively high speeds and impacting of looped and tangled fibers becomes highly probable.

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In the second paper of our series (3), an attempt was made to show some integration of the different factors (Introduction section) involved in hair breakage, rather than to suggest that one precludes the other as suggested by the following statement in the synopsis: "Extension or impacting hair fibers with flaws or damaged hair sections such as damaged wrapped ends produces short fiber fragmentation, while longer segment breaks may be produced in fibers with natural flaws (19) such as fiber twists, cracks or badly abraded (3,10,13,14) or chemically weakened hair or even knots (3,4)." (Reference citations in this quotation refer to references in the current paper.)

CONCLUSION

The phenomenon of hair breakage is a complex phenomenon involving multiple factors including progressive damage and the progressive propagation of flaws within the fiber as stated by Evans and Park, but more importantly it involves high localized stresses created in tangles. We believe that the literature clearly shows that the primary factors involved in hair breakage are the occurrence of tangles created by combing or brushing where one or more hair fibers are severely bent around at least one other hair. Therefore, high localized stresses are created by impact or pulling through that tangle. As a result, one or more hair breaks, either with or without flaws, under this condition. Other variables are clearly involved to determine the actual number of broken hairs and the type of fractures. These variables include hair type (primarily curvature), hair condition (treatments and wear), relative humidity or water content of the hair, and the specific grooming device as explained in the Discussion section. Brushing and combing certainly play a role in weakening hair, but they are unlikely to lead to pure fatigue breaks as claimed by the authors, especially under the low load levels experienced by the fibers.

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