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A study of damaged hair

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Synopsis—A SCANNING ELECTRON MICROSCOPE study of the morphological changes in human HAIR has revealed that these changes may be entirely attributable to the ABRASION normally associated with hair grooming. In particular, SHAMPOOING and BRUSHING can produce all of the observed changes detected in virgin hair. These changes are more deleterious in some cosmetically altered hairs. This appears to be attributable to a decrease in the disulphide bond content of these fibres, this decrease being brought about by the cosmetic treatment.

INTRODUCTION

In a study of fine changes in the surface architecture of human hair due to cosmetic treatment, Swift and Brown (1) have illustrated the stages of breakdown of human hair during cosmetic treatments. The natural appearance of hair, when first formed, displays a scale structure with smooth edges. This is subsequently transformed into stages they have characterized by: jagged scale edges, partial scale erosion, complete scale erosion, fibre splitting into two roughly hemi-cylindrical components and gross longitudinal splitting into many fibrous elements. These changes are generally referred to as weathering and the predominant cause is thought to be exposure to sunlight (2), which may result in a variation of the chemical and physical properties from the root to the tip of the fibres (3, 4).

By means of before and after treatments and the examination of the same hair fibres in the SEM, Swift and Brown (1) have established that some of these

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variations are due to combing of the hair and concluded that some may be due to natural weathering processes. They have also briefly mentioned some of the changes introduced into hair by perming and bleaching treatments. In a series of dynamic *in situ* experiments in a scanning electron microscope, Brown and Swift (2) have further demonstrated the deleterious effects of combing out tangles in hair. Such combing can cause cuticle cell lifting in tightly-looped fibres, as well as snapping fibres transversely or through the initial formation of a longitudinal fracture, when excess tension is applied during the combing.

In a study of the structure and properties of normal adult hair, Wall and Hunter (5) have similarly illustrated the production of jagged edges in the cuticle, and have shown features on the cuticle that they have attributed to sun and atmosphere exposure. DiBianca (6) has demonstrated many different types of damaged hair ends, but has not studied how these different types of damage occurred. Robbins and Kelly (7) have analysed the amino acid content of cosmetically-altered hair. They found that bleached and permanent-waved hair contained less cystine than unaltered hair, and correspondingly more cysteic acid residues. Bleached hair also contained slightly less tyrosine and methionine than unbleached hair. Miyazawa, Nozaki and Tamura (8) have made a similar study of the amino acid composition of hair damaged by treatment with cold-waving and hair bleaching lotions. They have also observed a reduction in the cystine content of human hair, with one bleaching condition reducing the cystine content from the normal of 13.9% to 5.0%, corresponding to an approximately 64% reduction in the disulphide bond cross-linking of the protein molecules.

These studies have illustrated the extent of chemical changes and the magnitude of physical changes introduced to hair, but have not yet confirmed how these observed physical changes were introduced. There is a need to understand how and why these deleterious physical changes to hair fibres occur in order to be able to prevent the damage. Some of this information is presented in this study.

Experimental

Samples of Caucasian hair were used in this study. This hair included many fibres displaying various degrees of splitting and hair damage, and samples that displayed no damage visible to the unaided eye. No attempt was made to differentiate between hair of different texture or condition.

The fibres were mounted on stubs so that the tip, root and portions of the mid shaft of each fibre could be examined in a scanning electron microscope (JSM2). The mounted fibres were coated with approximately 500 Å of gold prior to examination. They were examined for variation of scale structure along and between fibres, extent of scale damage and removal and degree of splitting of ends. The findings were correlated with the known history of the hair, and attempts were made to ascertain what caused the observed changes by reproducing the damage in controlled laboratory experiments.

The study was divided into two sections: the examination of virgin hair, that is, hair that had not been dyed, bleached, permed or otherwise treated, and cosmetically altered hair, hair that had received one or more of these types of treatments.

Results

Virgin hair

In common with the findings of Wall and Hunter (5) this study has shown that there was very little difference in fibre appearance between fibres from different people. The great variation detected was along fibres from root to tip and this variation was similar for all the fibres studied. This variation is reported below.

Fig. 1 shows a micrograph of a hair fibre, taken near the root, indicating the natural appearance of hair that is free from externally promoted defects (1). A few millimetres from the root the scale edges became jagged. For most of the fibres examined this jagged scale edge appearance, *Fig. 2*, represents the typical appearance of most of the fibre length.

Previous researchers (1, 2) have concluded that some of this change is due to the mechanical damage caused by brushing, combing and handling, and that some contribution to this deterioration may be due to weathering by exposure to rain, sunlight and dirt. Some of the fibres examined in this study had been shampooed and towel-dried three or four times per week, given minimal combing, approximately five comb strokes per day, were hardly ever exposed to sun or rain and had never been brushed. This abrasion of the scale edges still occurred in this hair, see *Fig. 2*. It seems probable that this deterioration of scale edge appearance was, in this case, due almost entirely to the wet abrasion associated with shampooing and towel drying.

To check the effect of wet abrasion on the cuticle, two experiments were performed. In one study, a child's hair was lightly shampooed, approximately once every week to minimize wet abrasion, and given minimal brushing and combing. The majority of the fibres examined from this child displayed a fibre appearance similar to that shown in *Fig. 1*. In the second experiment, a group of fibres from the above study were wet and rubbed vigorously between the hands to simulate shampooing and towel-drying. It was found that this action produced deterioration similar to that displayed in *Fig. 2*. From these observations it was concluded that the wet abrasion associated with shampooing and towel-drying was a dominant factor in the deterioration of scale edge appearance, at least amongst the persons studied.

With the exception of hair that had only been lightly shampooed, all other hair studied always displayed this deterioration of scale edges. However, some hair fibres displayed damage beyond that shown above. As reported by Swift and Brown (1), the next stages of fibre damage that were observed were partial, followed by complete scale removal, see *Fig. 3*. Again, by rubbing wet hair fibres in a manner that simulated shampooing, it was found that it was possible to remove completely the scale structure from the fibres. Similar rubbing of dry fibres did not produce the same degree of scale damage. Thus it seems probable that shampooing is a contributing factor to complete scale removal.

At this stage no assessment has been made of the role of hair brushing and combing in the damage to and removal of scales, although it seems probable (2) that these actions could also produce deterioration in the cuticle.

Amongst the hair fibres studied, it was found that complete scale removal only occurred in the last few centimetres. Once complete scale removal had occurred splitting of the fibre end into two, three or more longitudinal sections usually occurred, see *Fig. 4*.

Attempts were made to reproduce this type of damage. It was found that brushing a group of fibres that had been subjected to simulated shampooing caused the ends of some of the fibres to split, indicating that shampooing and brushing alone is sufficient to cause the ends of hair fibres to split. At this stage, no attempt has been made to ascertain which of these two actions is most responsible for the production of splitting, or what other procedures can cause splitting.

It was noted during the brushing trials that when a fibre had split longitudinally, it was common for the individual splits to fibrillate, see *Fig. 5*. Continued brushing caused these fibrillated regions to break, *Fig. 6*, thus producing a fibrillated end fibre.

The appearance of split ends could vary quite considerably from the simplified breakdown pattern shown in *Figs 4*, *5* and *6*. Some of these variations have been shown by Swift and Brown (1) and DiBianca (6). There is a shortening of fibres associated with the rupture of these fibrillated ends and this shortening appears to keep this type of damage restricted to the last few centimetres of a fibre shaft. These observations have illustrated that shampooing and brushing alone are sufficient to transform the hair from its natural state, *Fig. 1*, to split ends, *Figs. 5* and *6*. It seems probable that these grooming treatments of shampooing and brushing are the dominant factors in the physical deterioration of virgin hair. Weathering and exposure to sunlight would appear to be minor effects. If a sample of hair is just stored for hundreds of years, this type of damage does not occur (1), indicating that the deterioration is not an ageing process.

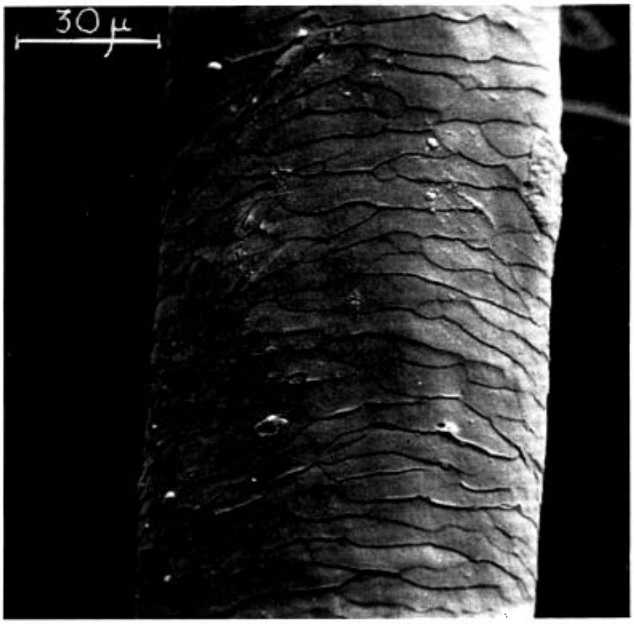

Figure 1. Typical appearance of human hair within a few millimetres of root. × 640.

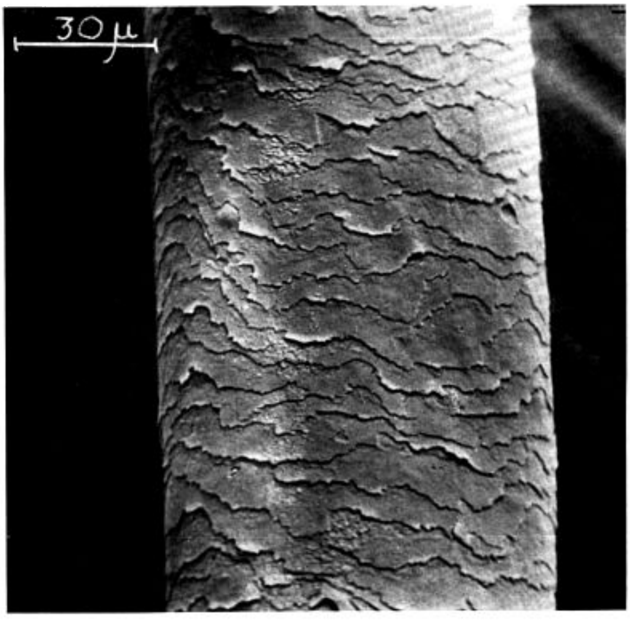

Figure 2. Typical appearance of human hair over most of the mid-shaft. The deterioration of scale edge appearance can be caused by shampooing alone. × 640.

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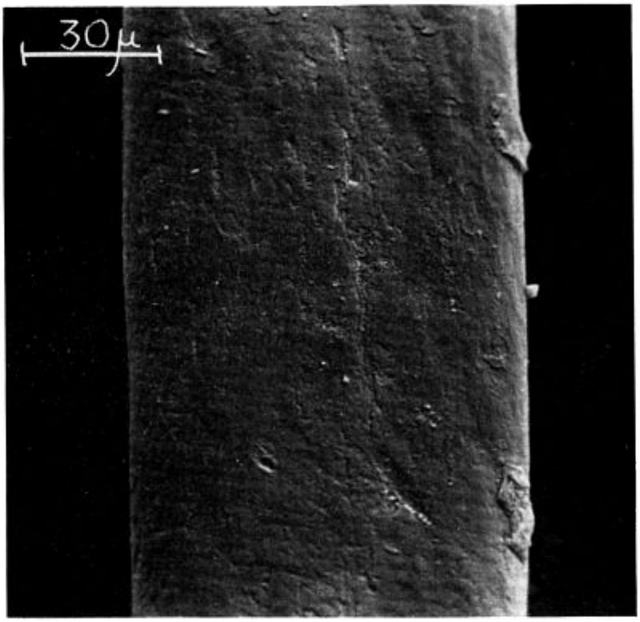

Figure 3. Complete cuticle removal near the ends of long hair. × 640.

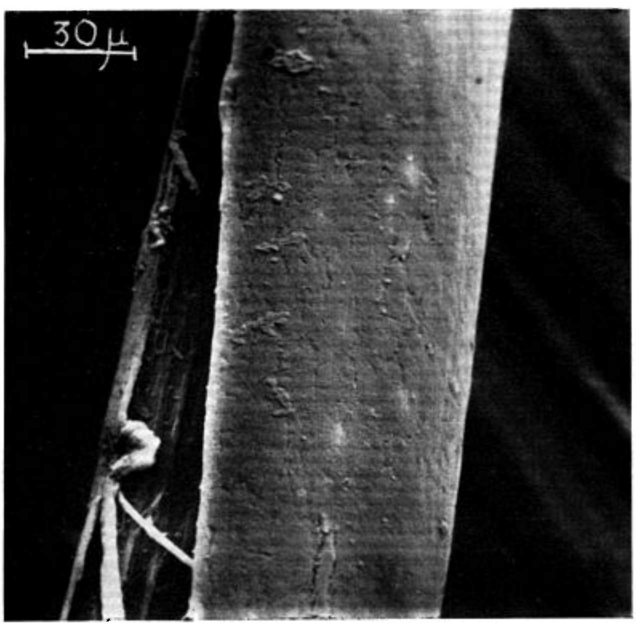

Figure 4. A longitudinal split near the end of a fibre. × 480.

Figure 5. A hemicylindrically split fibre segment, fibrillating at cortical cell boundaries. ×480.

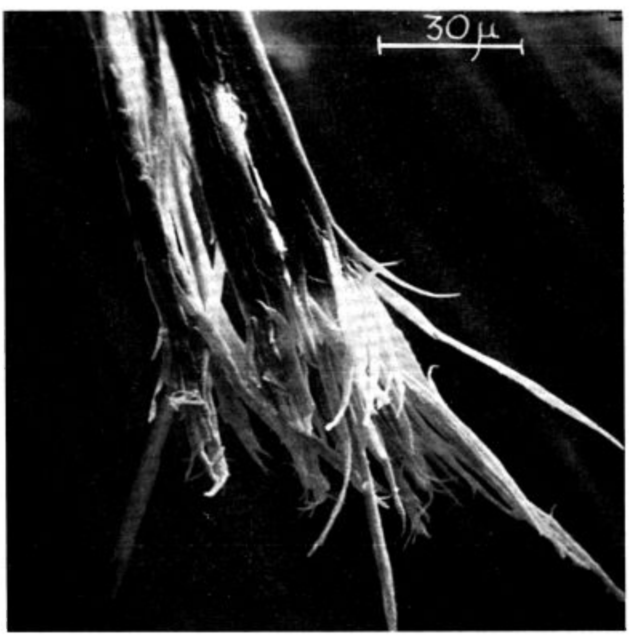

Figure 6. A fibrillated end fibre caused by the rupture of a fibrillating region. ×640.

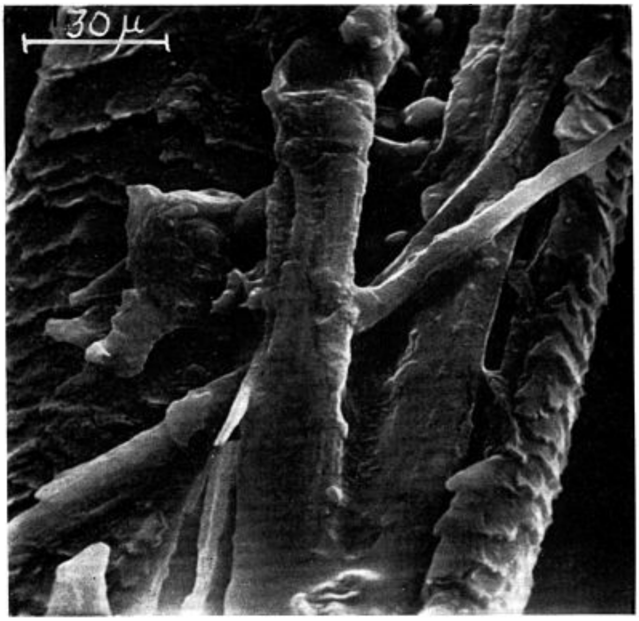

Figure 7. Fibre splitting in permanently-waved hair. ×640.

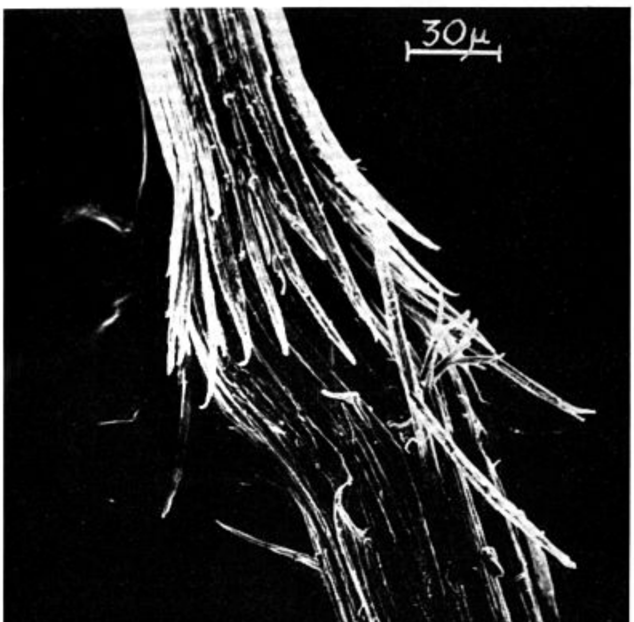

Figure 8. Shaft damage in permanently-waved hair. This damage was detected about 10 cm from the end of the fibre. ×400.

Cosmetically-altered hair

Cosmetically-altered hair had an appearance very similar to virgin hair, when no split ends were detected. The hair appearance shown in *Figs 1–6* for virgin hair, can also be seen in cosmetically-altered hair. However, there are also other types of breakdown associated only with cosmetically-altered hair.

Fig. 7 shows a split end from hair that has had one permanent-wave application. Unlike virgin hair, where splitting was only observed after almost all of the cuticle was removed, hair that had been permed or bleached was often observed to split whilst the cuticle was still clearly visible.

It was observed that splits and general shaft damage could also occur well away from the end. *Fig. 8* shows shaft damage detected about 10 cm from the end of a fibre that had been permed once and the perm did not 'take'.

The third important factor of cosmetically-altered hair was the extent of splitting. Virgin hair less than 15 cm long was hardly ever observed to split, whilst cosmetically-altered hair less than 15 cm long was often observed to split. This was detected as most likely to occur when a perm 'went wrong' or did not 'take', and on some bleached hair. Also, the splits and shaft damage associated with hair that had been permed or bleached, was generally observed to be far more severe than for virgin hair. That is, cosmetically-altered hair was observed to contain far more of the hair categorized as fly-away fibre (6) than virgin hair, for hair fibres of the same length.

The reason for this additional deterioration associated with cosmetically-altered hair is not immediately apparent. Swift and Brown (1) have shown that very minor changes in the surface structure of hair occur immediately after perming and bleaching, but these are not likely to be directly responsible for the observed additional damage. It is probable that these processes have chemically altered and weakened the hair and then during subsequent physical treatments, the altered hair is unable to withstand the abrasion normally associated with hair grooming to the same extent as can the virgin hair, and a greater degree of fibre splitting results.

Robbins and Kelly (7) and Miyazawa *et al.* (8) have found a reduction in the cystine content of bleached and permanent-waved hair. It is primarily the cystine content of keratin fibres, through the cross-linking associated with the disulphide bonds, that gives these protein fibres their high mechanical stability. It seems probable that the reduced fibre cross-link content associated with these treatments is responsible for loss of physical strength associated with these fibres.

Feughelman and Chapman (9) have shown that the relative cross-link density of keratin fibres can be ascertained by a determination of the diametral swelling of the fibres in 98% formic acid. This provides a convenient method for the determination of a relationship between fibre cross-link and splitting caused by the mechanical abrasion associated with hair grooming.

Virgin hair, when immersed in formic acid, swelled diametrally approximately 35% above the diameter of the dry fibre. Cosmetically-altered hair samples swelled to different amounts. Some fibres swelled the same as or only a little more than virgin hair, approximately 35–40% above the diameter of dry fibres. Other fibres were observed to swell to over 100% more than their dry diameter, indicating (9) an approximate 50% loss of disulphide cross-link content. Miyazawa *et al.* (8) have also observed similar reductions in the cross-link content of cosmetically-altered hair.

As a general observation, it was noticed that the fibres displaying greatest diametral swelling in formic acid also displayed the greatest tendency to split. No direct correlation was obtained between diametral swelling in formic acid and degree of splitting because it appears that the degree of splitting depends upon grooming conditions as well as disulphide bond content, and therefore no direct correlation could be expected to exist. It was also noticed that persons with hair that swelled more in formic acid were less satisfied with the appearance and condition of their hair. It seems likely that the cross-link content of the hair is at least partially responsible for the condition and manageability of the hair. That is, a reduction of the cross-link content of the hair, which may be introduced by some cosmetic treatments, results in a reduction of the ability of fibres to withstand the abrasive forces normally associated with hair grooming, causing an increase in hair damage during grooming, and appears to result in a loss of manageability of the hair.

Discussion

The results presented above indicate that the structural changes observed in hair fibres can be due entirely to the mechanical abrasion associated with normal hair grooming. This study has demonstrated that shampooing of virgin hair is sufficient in itself to damage and completely remove the cuticle. It is, of course, probable that some other treatments may also produce the same effect, but these have not yet been exhaustively investigated. It also appears that brushing of the hair contributes to damage to the cortex, and is at least partially responsible for the production of split ends in hair. No attempt has yet been made to determine the relative roles played by all of the hair grooming processes in breakdown of hair fibres.

Some cosmetically-altered hair is more prone to mechanical breakdown during grooming than virgin hair. This hair exhibits a greater tendency to swell in formic acid, indicating a loss of cross-link content resulting from the cosmetic treatment. It appears that the cosmetic treatment has reduced the cross-link content of the hair and that this has rendered the hair less able to withstand the mechanical abrasion associated with hair grooming, resulting in earlier splitting of the fibres.

Hydrogen bonds represent another useful form of cross-linking. Hydrogen bonds are reversibly broken every time hair is wet and are reformed again when it dries. Because of the decrease in hydrogen bonding, wet hair is completely unmanageable. Observations made during this study have indicated that wet hair is far more susceptible to damage during grooming than dry hair, and it would thus appear that minimal handling and brushing of wet hair could reduce the extent of physical damage to the hair.

Conclusion

This study has shown that the mechanical deterioration of hair which results in the production of split ends can be entirely attributable to the abrasion associated with hair grooming. It has also indicated that the increased tendency of hair to split after cosmetic treatments, particularly perming and bleaching, appears to be due to a reduction in the cross-link content of the fibres.

To prevent this mechanical damage minimum brushing and shampooing would appear to be desirable. Prevention of damage to the disulphide bond content of the hair fibres would also appear to be desirable to reduce splitting and improve the manageability of hair. There would also appear to be some advantages in increasing the cross-link content of hair by the introduction of cross-linking molecules. The additional cross-linking would retard fibre swelling when wet and possibly increase the wet abrasion resistance of the hair. It is also possible that such a treatment would improve the manageability and condition of the hair as well as being able to impart a permanent change of shape to the fibres. Studies in these directions are continuing.

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