J. Cosmet. Sci., 52, 103–118 (March/April 2001)

Ultraviolet damage on natural gray hair and its photoprotection

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Accepted for publication February 28, 2001.

Synopsis

The physicochemical properties of natural gray hair obtained from the heads of individuals and as well as commercial samples were investigated. No statistically significant differences were observed in terms of their central maximum diameter, central cross-sectional area, central ellipticity, average tensile strength, and average extent of transverse swelling between gray and black hair. The correlation between the elongation and the contraction of the cross-sectional area of hair fibers during extension was established as a statistically linear function, with a coefficient of 0.758. The damage on natural gray hair from ultraviolet (UV) irradiation were assessed by measuring the following parameters: hair color, Young's modulus, stress-to-break, wet combing force, dynamic advancing contact angle, tryptophan damage, cuticle abrasion, and transverse swelling of hair fiber in 0.1 N NaOH solution. It has been found that gray hair undergoes more severe UV damage and needs more UV protection than dark brown hair. Experimental results indicate that the quaternized UV absorber, cinnamidopropyltrimonium chloride (CATC), delivered from a simple shampoo system, is more substantive on hair and more effective in protecting hair from UV damage than a conventional UV filter. CATC also provided an additional conditioning benefit on hair.

INTRODUCTION

The influence of sunlight and ultraviolet (UV) light on both untreated and cosmetically treated human hair has been studied extensively by a number of researchers. Recently Ratnapandian *et al.* (1) studied the role of moisture in the photolysis of melanin-free virgin Piedmont hair and presented a free-radical mechanism to explain the photolysis processes. Changes in wet mechanical properties, swelling behavior, and IR spectrum were monitored and used to determine the degree of damage. The authors observed that hair exposed to UV irradiation sustains weathering damage under all conditions of relative humidity and found that exposure at 30% RH causes the least damage. Hoting and Zimmermann (2–4) studied photochemical alterations in human hair and sunlight-induced modifications in bleached, permed, and dyed-brown human hair. They measured changes in hair color, tensile strength, and lipid compositions before and after irradiation with UV-A, UV-B, visible (VIS), and IR light. They found that blond hair is less photostable than black hair and that chemically treated hair exhibits significant color fading and yellowing after UV exposure. They also reported that chemically bleached hair needs additional protection against photochemically induced protein and

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lipid modifications. Jachowicz *et al.* (5) and Pande and Jachowicz (6) used fluorescence spectroscopy to quantify tryptophan photodecomposition after UV irradiation. They found that weathering caused hair to undergo a significant loss in tryptophan, as well as other chemical changes affecting keratin structure, such as the oxidation of disulfide bonds to cysteic acid. Deflandre *et al.* (7) investigated photoaging and photoprotection of natural hair using the FT-IR technique and found that water inside the hair fiber is a necessary prerequisite to photooxidation or photobleaching of hair during UV exposure. They concluded that natural melanin in the hair is, at most, a weak means of protecting hair against the photodegradative action of solar light. Giesen *et al.* (8) studied the hair protection behavior of different UV filters and found that broad-spectrum filters such as benzophenones were particularly effective in protecting hair against discoloration and against losses in fiber strength and breaking force. They also observed that an oil-based product such as a shine spray containing oil-soluble UV filter was more effective in UV protection than setting lotions, which contained water-soluble UV filters. Gonzenbach *et al.* (9) studied UV damage on human hair and compared ten different UV filters. Their findings suggest that the choice of UV filter and the careful optimization of the formulation are crucial in developing a final product that can protect human hair from solar UV effectively. They used a colorimetric method to analyze the content of tryptophan in the hair before and after UV irradiation. They also found that blond hair is more susceptible to UV damage than black hair. Korner *et al.* (10) studied changes in the content of 18-methyl eicosanoic acid (18-MEA) in wool after UV irradiation. They found that exposing wool fabric to artificial sunlight resulted in a loss of approximately 45% of the original 18-MEA content and that the branched-chain fatty acid 18-MEA was more sensitive to UV irradiation than the saturated, straight-chain acids with 16 and 18 carbon atoms.

Until now there have been very few published studies on UV damage in natural gray hair. Only one paper, from Hollfelder and his co-workers, studied the chemical and physical properties of pigmented and non-pigmented (gray) hair (11). They found no statistically significant differences between pigmented hair and gray hair in terms of their fiber ellipticity and fiber break strength (wet). However, they observed that the average diameter of gray hair was statistically larger than that of pigmented hair and that the cystine content in gray hair was less than that in pigmented hair. They reported that gray hair showed a significant decrease in both wet breaking strength and cystine content after irradiation. After short periods of oxidation treatment, the level of cysteic acid in gray hair was found to be slightly higher than that in pigmented hair. They concluded that, in most cases, non-pigmented hair became more damaged after weathering than pigmented hair. However, no details about the test methods were reported.

This paper represents the results of our recent studies on the physicochemical properties of natural gray hair and the effects of UV irradiation on these properties with and without UV protection. The central diameters, central cross-sectional area, central ellipticity, extent of transverse swelling, stress-to-break, and strain-to-break of gray and black hair fibers were measured to determine if there were statistical differences between these types of hair. Gray and black hair samples were obtained from the heads of individuals for comparison. The UV study itself consisted of treating natural gray and virgin brown hair tresses with various and simple shampoo systems, which contain either a conventional UV filter or a quaternized UV absorber. Then the hair samples were irradiated with UV light for fifteen or twenty consecutive days. The following param-

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eters were measured and used to determine the extent of hair damage and assess the relative effectiveness of the two UV filters in sun protection: hair color change, tryptophan damage, tensile strength, wet combing force, dynamic advancing contact angle, cuticle abrasion, and fiber swelling.

MATERIALS AND TEST METHODS

CHEMICALS

The following chemicals were used:

a. Octylmethoxycinnamate (OMC), Escalol 557, ISP Van Dyk Inc., Belleville, NJ
b. Cinnamidopropyltrimonium chloride (CATC), Incroquat UV-283, Croda Inc., Parsippany, NJ
c. Ammonium laureth sulfate (ALS), Standapol EA-2, Henkel Corp., Hoboken, NJ
d. Sodium lauryl sulfate (SLS), Standapol WAQ-SP, Henkel Corp., Hoboken, NJ

HAIR SAMPLES

Virgin dark brown and 90% natural gray hairs were purchased from International Hair Importers & Products Inc., Bellerose, NY. Four tresses each (about 3 grams) of natural gray and virgin brown hair were used for the UV study. Hair samples were also collected from the heads of four graying individuals (with no known history of chemical treatments). These hair fibers were separated manually into pigmented (black) and non-pigmented (gray) fibers for evaluations and comparisons to each other.

TREATMENT OF HAIR SAMPLES

Test hair tresses were washed with 5% ALS solution (hair/solution weight ratio = 1/10) for three minutes and rinsed thoroughly under running tap water (~20°C) for three minutes at an approximate flow rate of 75 ml/sec. The tresses were then air-dried and labeled as tresses 1–4. Tress 1 was used as a control without any UV exposure. Tresses 2, 3, and 4 were treated with 10% SLS aqueous solutions containing 2% CATC, 2% OMC, and no sunscreen active, respectively. Tresses 2, 3, and 4 were soaked in their respective formulations for five minutes at 35°C at the start, and then every 24 hours thereafter. Following each treatment, the tresses were rinsed under running tap water (~20°C) for 30 seconds at the flow rate of about 75 ml/sec and then returned to an environmentally controlled chamber for further UV irradiation.

IRRADIATION OF HAIR

Four UV-B lamps (F20T12, Atlantic Ultraviolet Corp., Hauppauge, NY) were installed in an environmentally controlled chamber, which was set at a constant temperature of 27°C and a constant relative humidity of 65%. The hair tresses were positioned 10 cm from the UV lamps. Irradiation energies were determined using PMA UV-B and UV-A detectors (Solar Light Co. Inc., Philadelphia). The applied wavelength range and irradiance were 280–320 nm, 0.14 mW/cm^2 for UV-B and 320–400 nm, 0.49 mW/cm^2 for

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UV-A, respectively. The hair tresses were rotated constantly to assure uniform exposure to the UV irradiation. On days 3, 7, 15, and 20, fifty fibers from each hair tress were collected for evaluation.

HAIR COLOR

Computer images of the four test hair tresses were taken after UV irradiation and used to assess changes in color by naked eyes. The color of the treated samples, tresses 2, 3, and 4, was viewed and compared to the color of tress 1, the control without UV exposure. The color of the hair tresses was also measured analytically with a LabScan XE spectrophotometer (Hunter Laboratories, Virginia). The changes in color before and after UV irradiation for each tress were expressed as the total difference in color (DE), difference in light index (DL), difference in blue-yellowing index (Db), and difference in yellowing index (DYI) using the CIEL*a*b* system.

HAIR DIAMETERS AND CROSS-SECTIONAL AREA

A laser-scanning micrometer (Mitutoyo, LSM-5000) was used to measure the diameters and the cross-sectional areas at the middle section of each fiber. This instrument employs a 1.0-mw 670-nm wavelength laser. The micrometer was calibrated using standard calibration wires of known cross-sectional area. Test hair fiber samples for the laser-scanning micrometer were 3.0 cm in length and prepared using a metal-tube sample mounting system supplied by Dia-Stron Limited, UK. After measuring the cross-sectional area, test samples were transferred to the autosampler attached to a miniature tensile tester (MTT-670, Dia-Stron Ltd, UK) for tensile strength measurements.

TENSILE STRENGTH

The breakage resistance of single fibers was measured using a Dia-Stron MTT-670 attached to an autosampler in an environmentally controlled chamber at a constant temperature of 23°C and a relative humidity of 50%. The cross-sectional area data of each tested hair fiber was imported into MTTWIN software for automatic calculation of Young's modulus of each single fiber. The original cross-sectional area of each hair fiber was also used to calculate the contracted cross-sectional area at its break extension (strain-to-break). Then the revised cross-sectional area at the strain-to-break was used to calculate the stress-to-break. The average values of these parameters were calculated for 15 fibers randomly collected from each hair tress.

WET COMBING FORCE

The wet combing forces (peak load and total work) of test hair tresses were determined using a Dia-Stron MTT-160 at room temperature. Each test hair tress had a length of 18 cm. MTT operational parameters were set to the following: hair sample size of 30 mm; force range of 2000 gram; and combing speed of 120 mm/min. Five combing trials for each tress were conducted to calculate the average value. The percent changes in wet combing forces were calculated using the control value of the same hair tress before UV irradiation.

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DYNAMIC CONTACT ANGLE

The dynamic advancing contact angle at the interface between a hair fiber and de-ionized water was measured automatically using a Cahn DCA-315 dynamic contact angle analyzer at room temperature. The average dynamic advancing contact angle value was obtained from measurements of ten fibers randomly collected from each hair tress.

TRANSVERSE SWELLING

The change in the central cross-sectional areas of hair fibers immersed in 0.1 N NaOH solution was automatically measured using the Mitutoyo LSM-5000 for five minutes at room temperature. The average percent increase in the cross-sectional area of ten fibers randomly collected from each hair tress was calculated and used as the average extent of transverse swelling.

RESULTS AND DISCUSSION

In the following section, the data will be presented to showcase the effects that a quaternized UV absorber, CATC, had on various properties of gray hair under UV irradiation. The performance of CATC is compared to the performance of a conventional neutral sunscreen agent, OMC. The substantivity of CATC or OMC on a hair surface, as delivered from a simple shampoo test system—aqueous 10% SLS solution containing 2.0% actives of UV filter—was determined for comparison. It was found that CATC was quite substantive on gray hair, its substantivity being 4.50 mg per 100 grams of hair. On the other hand, only a trace amount of OMC was detected on the hair surface treated with the same surfactant system. This significant difference in substantivity likely explains why CATC is superior as a UV protector on hair in comparison to the conventional UV filter, OMC, as delivered from the tested shampoo system.

DIFFERENCES BETWEEN GRAY AND BLACK HAIR

Four pairs of hair samples were obtained from four panelists, respectively, including three men and one woman. Each pair of hair samples consisted of 20 black and 20 gray hair fibers from one individual head. The fifth pair of hair samples consisted of 20 black and 20 gray hair fibers, which were randomly collected from a commercial 90% gray hair tress. Data on maximum center diameter, D_{max}, minimum center diameter, D_{min}, center cross-sectional area, A, center ellipticity, E, strain-to-break, stress-to-break, and swelling are summarized in Table I. A t-test was performed for statistical analysis of the data using Microsoft Excel.

Based on t-test results, no statistically significant differences were found between these black and gray hair fibers in terms of their center maximum diameter, center ellipticity, center cross-sectional area, stress-to-break, strain-to-break, and transverse swelling. The only difference observed was the center minimum diameter: the black fibers had slightly larger center minimum diameters than those of gray fibers.

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Table I
Physicochemical Properties of Gray and Black Hairs

Hair type	Gray	Black	Statistical difference
D_{max} (mm)	0.0832 ± 0.0145	0.0846 ± 0.0122	No
D_{min} (mm)	0.0582 ± 0.0064	0.0616 ± 0.0062	Yes
A (mm^2)	0.003835 ± 0.000951	0.004124 ± 0.000886	No
$E = D_{max}/D_{min}$	1.433 ± 0.218	1.377 ± 0.169	No
Stress-to-break (Gpa)	$(3.43 \pm 0.58) \times 10^8$	$(3.31 \pm 0.65) \times 10^8$	No
Strain-to-break (%)	50.39 ± 6.94	49.32 ± 7.22	No
Swelling (%), 5 min	11.78 ± 3.04	12.43 ± 2.31	No

CHANGES IN HAIR COLOR

The differences in color between the four gray hair tresses after 15 days of UV irradiation are very apparent by visual inspection. The hair tresses were put on the flat glass of a Hewlett Packard ScanJet 6200C scanner and scanned. The computer images of the four hair tresses are presented in Figure 1. It can be seen that tress 2 retained its original color and had virtually the same color as the control, tress 1, but that tresses 3 and 4 developed a yellow tint compared with tress 1.

The determined changes in light index, DL, in blue-yellow index, Db, in total color difference, DE, and in yellowing index, DYI, for each tress before and after UV irradiation are presented in Figure 2. It was found that all of the changes in color index values of tress 2 were minimal, meaning that very little color change took place in tress 2. It was also observed that the light index values (L) for tresses 3 and 4 decreased (DL < 0) after UV irradiation. This indicates that tresses 3 and 4 turned slightly darker than their original color. Their blue-yellow index values, b, and the corresponding yellowing index values, YI, of tresses 3 and 4 increased (Db and DYI > 0) after UV irradiation. This means that tresses 3 and 4 turned yellower in comparison to their original color. All of these changes in color index values are consistent with our visual observations.

The hair-yellowing effect suggests that a UV-induced degradation of hair was taking place. As noted by Roper and Finnimore, a light yellow residual color, or a newly formed yellow photochemical product, remains on hair following UV exposure (12).

To compare the effect of UV irradiation on hair color changes of different types of hairs, we studied color changes in dark brown hair according to the procedures described above. Data on DL, Db, and DE of brown hair exposed to 20 days of UV irradiation are presented in Figure 3.

Inspection of Figures 2 and 3 shows that the value of the total color difference (DE), 4.45, for the unprotected brown hair after 20 days of UV-B irradiation is smaller than the corresponding DE value of 7.42 for unprotected gray hair after 15 days of UV-B irradiation. This suggests that natural gray hair is more sensitive to color change than natural dark brown hair. It is also interesting to note that brown tresses 3 and 4 were somewhat lightened in color after UV exposure. Their light index values, L, were larger than their original values (DL > 0). This suggests that melanin in unprotected brown hair underwent photobleaching during UV irradiation. From Figures 2 and 3, it is seen that both gray and brown hair tresses treated with CATC had small changes in hair

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Tress1, No UV exposure Tress 2, CATC; Tress 3, OMC Tress 4, SLS

Figure 1. Color photo of gray hair tresses after UV irradiation.

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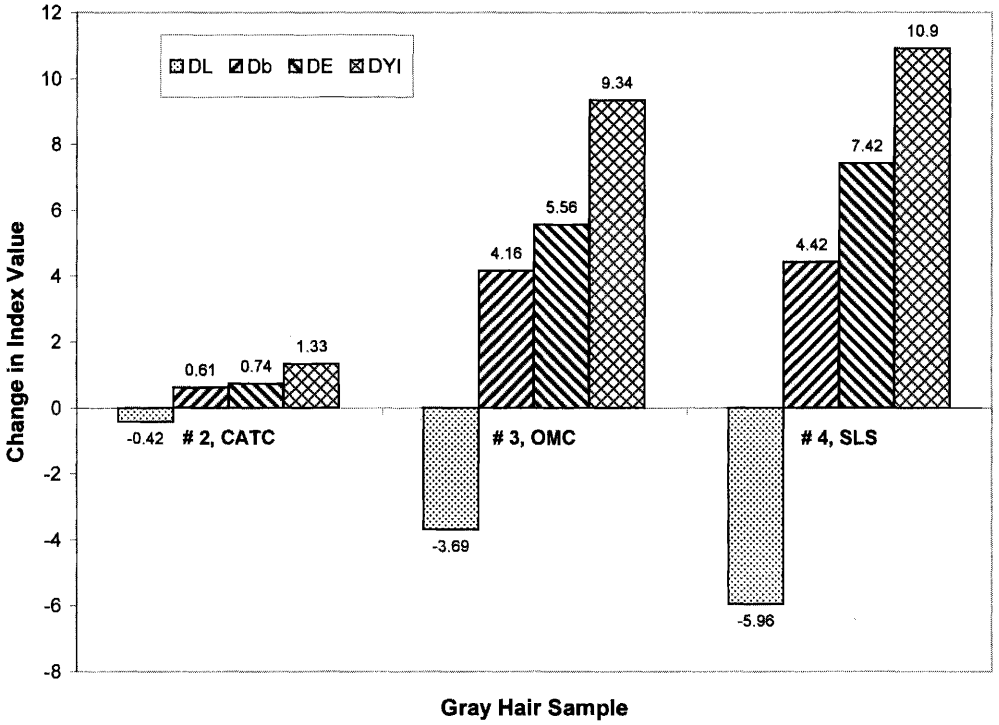

Figure 2. Change in color index values of gray hair tresses after UV irradiation.

color. This demonstrates that CATC is a very good UV absorber and protects hair from color fading.

CHANGE IN CROSS-SECTIONAL AREA WITH EXTENSION

As a solid fiber, it is known that the cross-sectional area of a hair fiber decreases with an increase in its length during the extension process. Since human hair consists mainly of α-keratin, a biological polymer, it is expected that the hair fibers exhibit viscoelastic properties. Therefore, the contraction in the cross-sectional area of a hair fiber during its extension process would not exactly be inversely proportional to the amount of its extension.

In order to find and establish the exact correlation between the length extension and the contraction of the cross-sectional area during the elongation process, we measured the center cross-sectional areas at different extensions for 100 single brown and gray hair fibers. The plot of the length extension vs. average contraction of the central cross-sectional area is presented in Figure 4. It was found that the correlation between the length extension and the average contraction of the center cross-sectional area is a statistically linear function. The determined ratio of extension to contraction is 1 to 0.758, which indicates that as a hair fiber is extended by 10%, its cross-sectional area only contracts about 7.58%. This coefficient was very useful, and used in calculations of the revised cross-sectional area at the strain-to-break.

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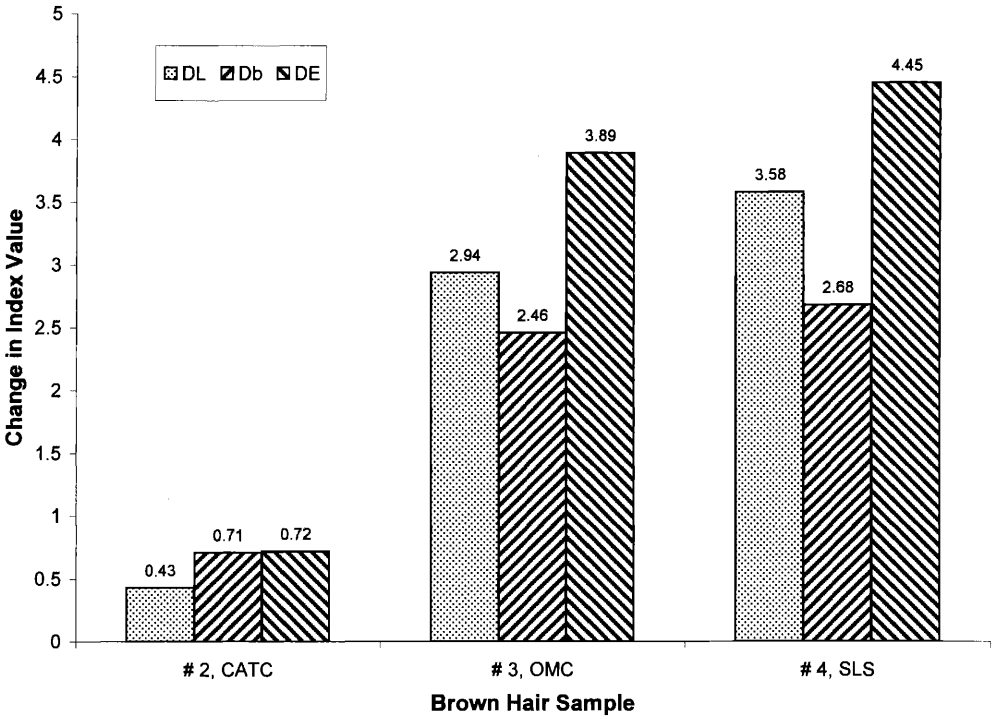

Figure 3. Change in color index values of brown hair tresses after UV irradiation.

CHANGE IN TENSILE STRENGTH

The changes in both the average Young's modulus and stress-to-break of gray hair samples after 15 days of UV irradiation are presented in Figure 5.

It is readily seen that after 15 days of UV irradiation, hair fibers from gray hair tresses 2, 3, and 4 retained 94.6%, 87.7%, and 76.6% of their initial Young's modulus, and 92.7%, 85.4%, and 78% of their initial stress-to-break values, respectively. All of these reductions in tensile strength indicated that the cortex of the hair fiber was damaged and that some portion of the disulfide bonds, hydrogen bonds, and salt bridges were likely modified. The above results clearly demonstrated that CATC helped to maintain the tensile strength of hair.

CHANGES IN DYNAMIC CONTACT ANGLE

Changes in the average dyanmic advancing contact angles of gray hair fibers after UV irradiation are presented in Figure 6. It is readily seen that the average advancing contact angles of hair fibers from tresses 3 and 4 decreased dramatically, which indicates that the characteristics of the hair surface were changed from hydrophobic to hydrophilic because of the surface damage. This increase in the hydrophilicity and wettability of the hair surface may be partially attributed to the loss of 18-MEA and other fatty acids on the hair surface (10). In contrast, only the hair fibers treated with CATC maintained their

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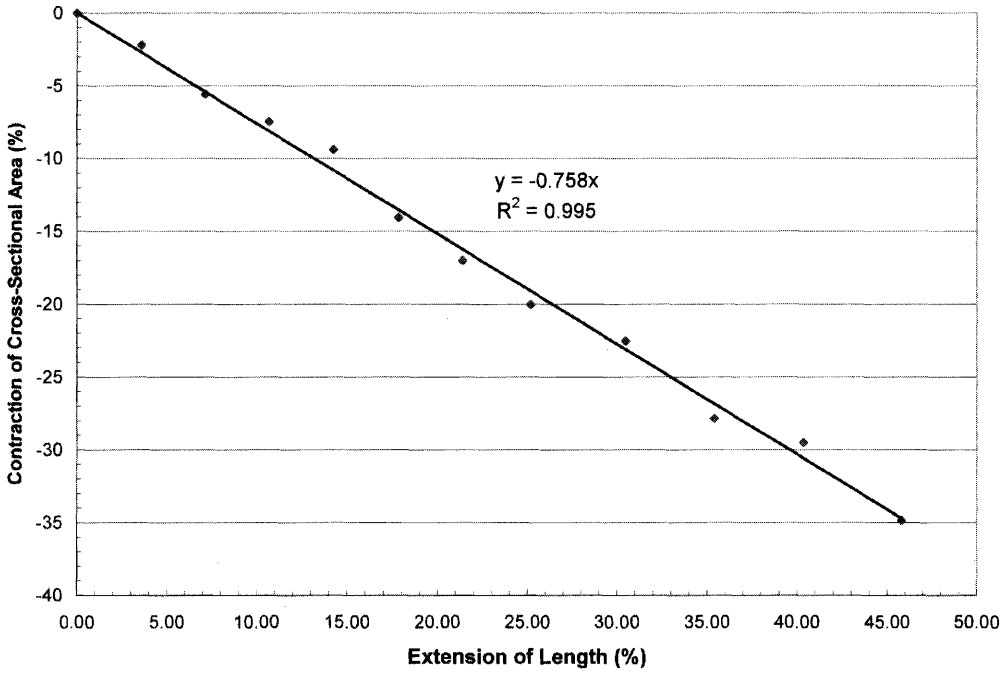

Figure 4. Plot of length extension vs. contraction of cross-sectional area of hair fibers.

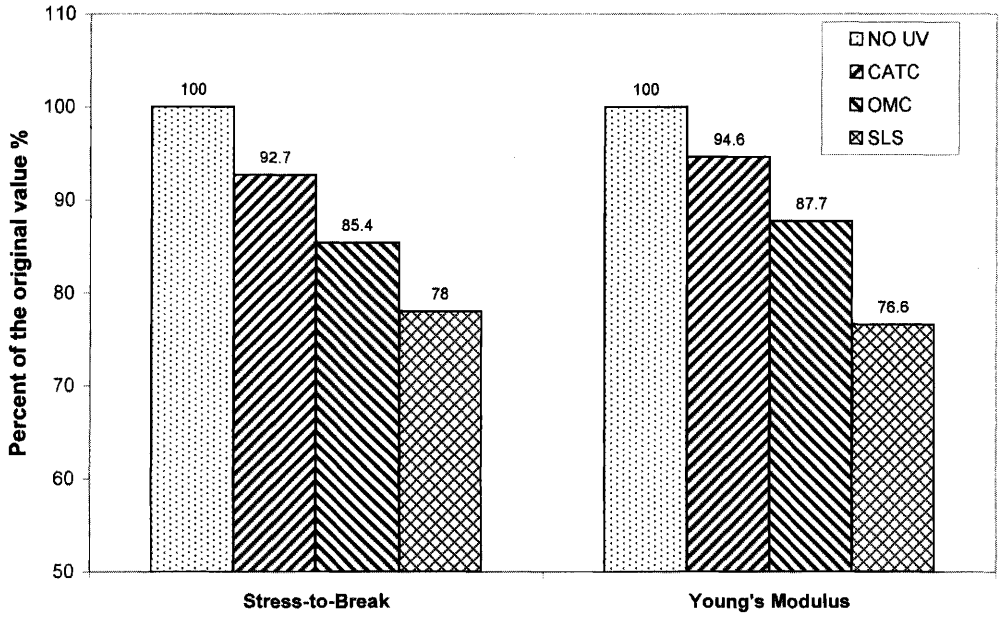

Figure 5. Changes in stress-to-break and Young's modulus after UV irradiation.

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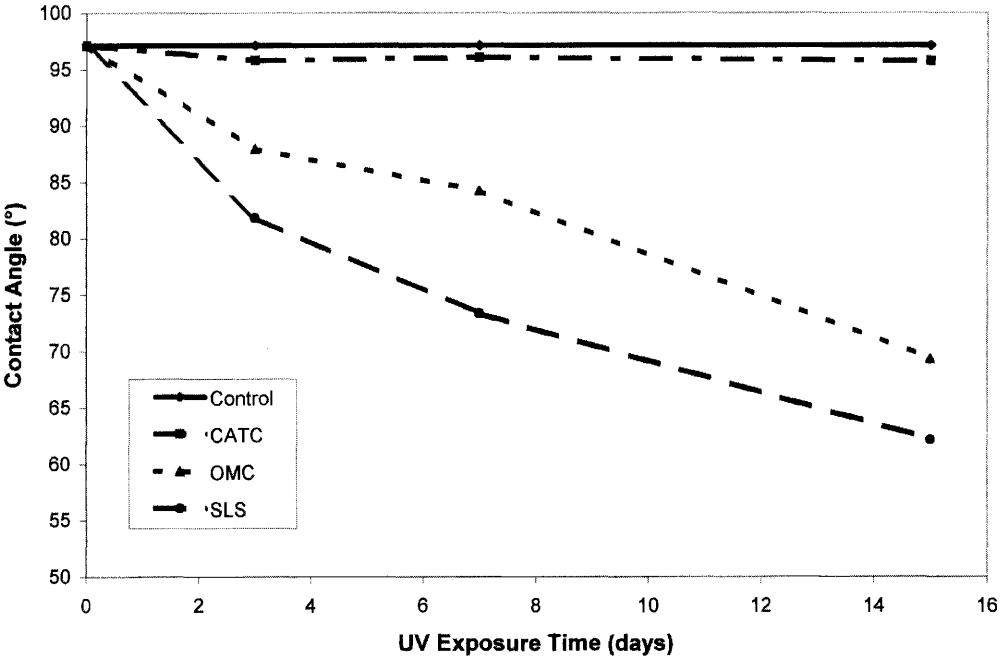

Figure 6. Changes in dynamic contact angle after UV irradiation.

hydrophobic surface, as indicated by essentially no change in the contact angle compared to those fibers that had not been exposed to UV.

As a quaternized ultraviolet absorber, CATC deposited on the hair surface to protect hair from UV penetration and also modified the hair surface. Therefore, the hydrophobic surface of tress 2 even after UV irradiation could be attributed to more than one mechanism: either photoprotection of the hair surface, preventing surface damage, and/or a conditioning effect as a result of its cationic nature. In order to differentiate between these two mechanisms, we washed a part of tress 2 with IPA to remove CATC thoroughly from the hair surface and then remeasured the contact angles. We found no significant difference in average contact angles between extracted and un-extracted hair fibers. This clearly indicates that the hair surface is protected from UV damage by deposited CATC. As alluded to above, the CATC deposited on the hair surface not only protects hair from UV damage, but also acts as a conditioner. Studies to determine the reduction in the wet combing force were conducted to validate this conditioning effect and are discussed in the section below.

REDUCTION IN WET COMBING FORCES

Data on the changes in the peak load and the total work of four test gray hair tresses before and after 15 days of UV irradiation are presented in Figure 7.

It is seen that the wet combing force increased more than 100% for hair tresses 3 and 4. These observed increases in hair frictional force may be related to the photochemical damages and subsequent removal of the epicuticle layer of hair lipids, such as 18-MEA, which play an important role in the surface properties of hair (5,10). This is also due in

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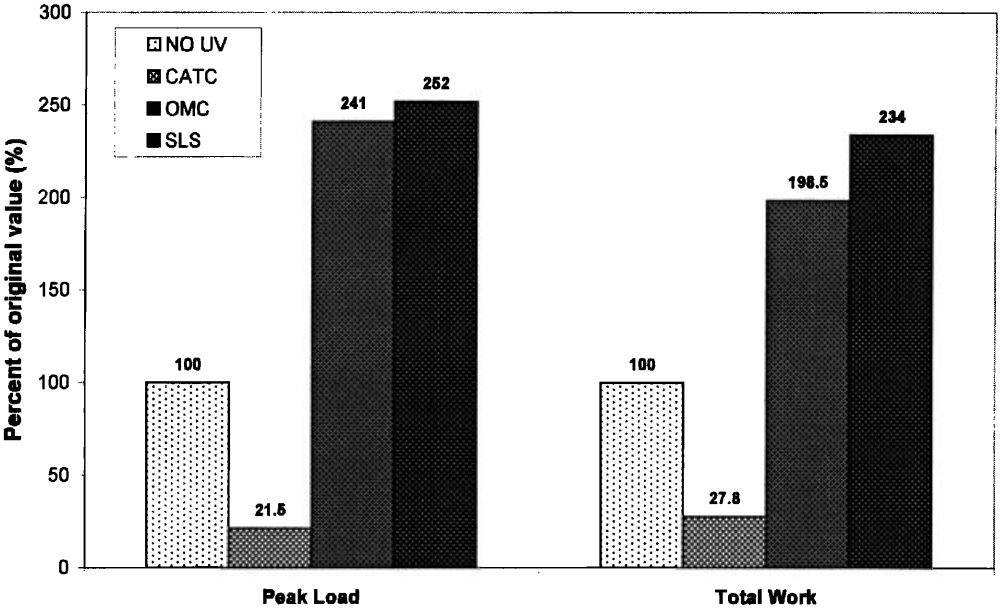

Figure 7. Changes in wet combing force after UV irradiation.

part to the oxidation of cystine to cysteic acid. As a result of the increased surface hydrophilicity (wettability), the wet combing force of these hair tresses increased dramatically. In contrast, the peak load and the total work for the hair tress treated with CATC were reduced 78.5% and 72.2%, respectively. This reduction in the wet combing forces for tress 2 clearly indicates that CATC provides a conditioning benefit in addition to its UV protective function.

SWELLING TEST

Radnapandian *et al.* (1) determined the extent of transverse swelling in a 0.1 N NaOH solution of Piedmont hair that had been irradiated for 300 hours at various RH levels. In a similar fashion, we determined the average increases in the center cross-sectional area of hair fibers after 15 days of UV irradiation. The data are summarized in Figure 8.

It is seen that the hair fibers treated with CATC showed almost the same amount of transverse swelling as the hair fibers without UV exposure. Hair fibers treated with 10% SLS exhibited the highest amount of swelling. Swelling increases with the loss of crosslinks inside the hair fiber (13). Hence, our experimental results suggest that hair treated with CATC retains a larger number of crosslinks compared to hair treated with either SLS/OMC or SLS. This interpretation is consistent with our test results of tensile strength. Alternatively, as suggested by Ratnapandian *et al.* (1), the degradation of protein in the hair fiber may cause swelling. Hair tresses treated with SLS or OMC had less UV protection, and the proteins may have been extensively degraded. Protein residues possessing molecular weights small enough to let them diffuse out of the fiber during immersion in 0.1 N NaOH solution may have left holes in the cortex allowing the NaOH solution to swell the hair. Hair treated with CATC experienced less protein

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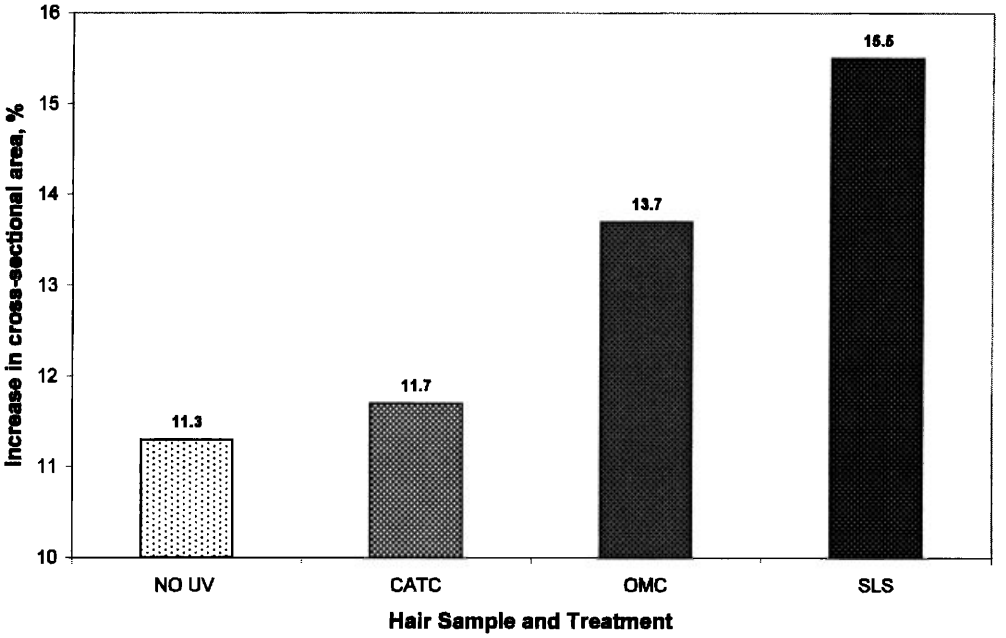

Figure 8. Transverse swelling of hair fibers after UV irradiation.

degradation, and the protein residues were large enough to be retained. This only leads to osmotic swelling of fiber, which is smaller in magnitude than the diffusion swelling caused by the loss of protein fragments.

TRYPTOPHAN DAMAGE

In order to compare the tryptophan damage on the surface of hair, we measured fluorescence intensities of four test gray hair tresses using a Fluorolog-3 spectrophotometer from Spex with a solid-sample accessory. The excitation wavelength was set at 295 nm and the tryptophan emission intensity was measured at 340 nm. The percent tryptophan damage (Trp damage) was calculated as $[(I_0 - I_d)/I_0] \times 100$, where I_d and I_0 represent, respectively, the tryptophan emission intensities from damaged hair and non-damaged hair (5). The emission intensity has been assumed to be directly proportional to the surface tryptophan concentration. The percent photoprotection was calculated as 1-Trp damage. The calculated Trp damage and percent photoprotection are presented in Figure 9.

After 15 consecutive days of UV irradiation, the unprotected natural gray hair (tress 4) lost about 85% of its surface tryptophan content. Gonzenbach *et al.* (9) reported 26.4% to 37.6% decreases in tryptophan content of untreated blond hair after 180 hours of exposure to simulated sunlight. Cegarra and Gacen (14) reported that the tryptophan content in wool decreased about 61% after 100 exposure hours in a Fade-Ometer. Jachowicz *et al.* (5) have indicated that the fluorescence technique probes only the surface layers of hair and detects tryptophan damage related to the residues of this amino acid located in the cuticles and/or outermost layers of the cortex. They reported 45% tryptophan loss for Piedmont hair under outdoor solar irradiation for only 65 hours. Our

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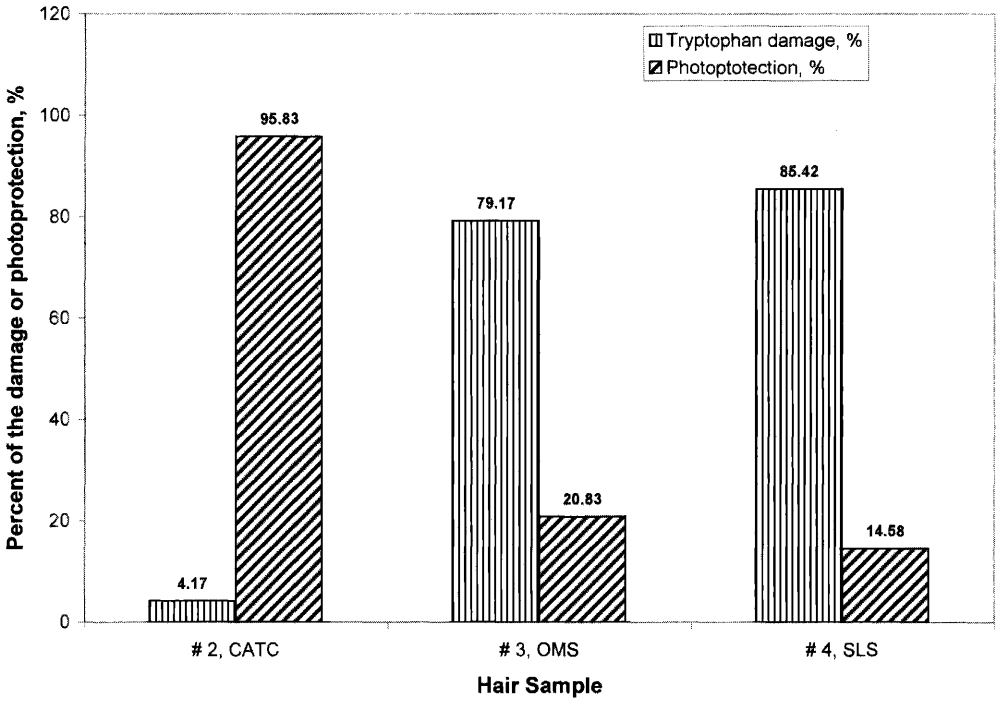

Figure 9. Tryptophan damage and photoprotection of different hair tresses.

experimental results are consistent with their studies. From Figure 9, it is clear that CATC provides very effective protection from tryptophan photodamage.

CUTICLE ABRASION

After UV irradiation, hair fibers from the four test gray hair tresses were taken and examined under SEM. No visible damage on the hair surface (cuticle appearance) was observed. In order to detect the structural damages in hair cuticles, we combed all these four test gray hair tresses with 1000 strokes using a combing wheel (one combing per second). After combing, we randomly collected hair fibers from these hair tresses and inspected them under SEM to determine the extent of cuticle abrasion. Four typical SEM pictures are presented in Figure 10.

It is seen that hair fibers from tresses 3 and 4 underwent more cuticle abrasion compared with those from tresses 1 and 2. These results indicated that more cuticle structural damages were taking place in tresses 3 and 4 than in tresses 1 and 2 during UV irradiation. This clearly demonstrates that the hair surface (cuticles) in tress 2 was protected by CATC from a combination of mechanical and UV damage.

COMPARISON OF UV DAMAGE IN GRAY VS. DARK BROWN HAIR

Some of the UV damage data for gray and dark brown hair tresses are summarized in Table II to demonstrate the effects of pigmentation on UV damage.

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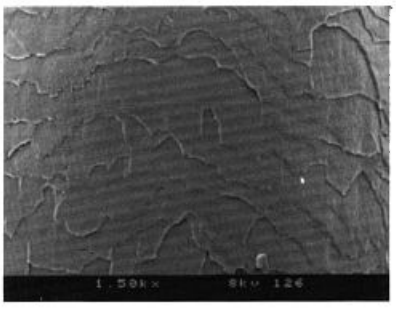

Fig. 10-a Tress 1 (No UV)

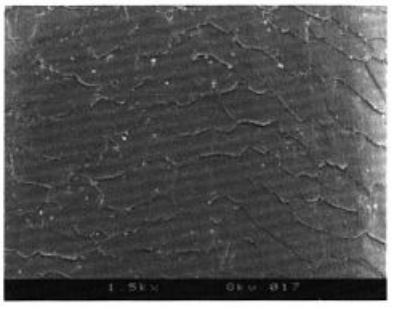

Fig. 10-b Tress 2 (CATC)

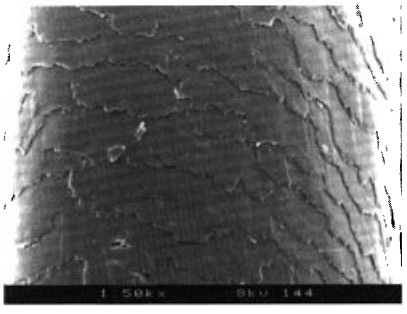

Fig. 10-c Tress 3 (OMC)

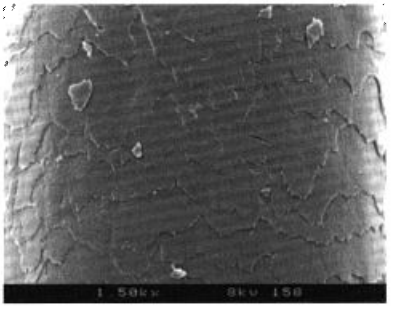

Fig. 10-d Tress 4 (SLS)

Figure 10. SEM pictures of hair fibers after 1000 combing strokes.

Table II
UV Damage on Gray and Dark Brown Hair*

	Gray hair			Dark brown hair		
	Tress 2	Tress 3	Tress 4	Tress 2	Tress 3	Tress 4
Hair treatment	CATC	OMC	SLS	CATC	OMC	SLS
Stress-to-break retention (%)	92.1	82.1	75.7	96.6	88.6	81.1
Tryptophan damage (%)	4.17	79.17	85.42	4.5	80.2	85.2
Difference in color (ΔE)	0.74	5.56	7.42	0.72	3.89	4.45

* Data collected for gray hair after 15 days of UV irradiation and for dark brown hair after 20 days of UV irradiation.

From the data in Table II it can be concluded that gray hair is more sensitive to UV irradiation and undergoes more severe damage than dark brown hair. These results clearly demonstrate that gray hair needs additional protection from UV exposure.

CONCLUSIONS

It has been shown that there are no statistically significant differences in the center maximum diameter, center cross-sectional area, center ellipticity, extent of swelling, stress-to-break, and strain-to-break between gray and black hair from the same heads

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(Table I). However, UV irradiation causes more severe damage on natural gray hair than on natural dark brown hair (Table II). The extent of UV damage can be assessed by the following measurements: a change in hair color (color fading or yellowing), a decrease in tensile strength (Young's modulus and stress-to-break), a decrease in dynamic advancing contact angle, a loss of tryptophan at the hair surface, and an increase in hair swelling in 0.1 N NaOH solution. It has been found that the quaternized UV absorber, cinnamidopropyltrimonium chloride (CATC), delivered from a simple rinse-off shampoo system, is more substantive on hair and more effective in protecting hair from UV damage than a conventional UV filter. CATC not only provides excellent UV protection for hair, but provides conditioning benefits as well.

ACKNOWLEDGEMENTS

The authors acknowledge Kevin Gallagher's encouragement and Dr. Rob Comber's invaluable help and discussions during the whole study.

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