J. Soc. Cosmet. Chem., 34, 361-382 (November 1983)

A comparative study of beard and scalp hair

EVA TOLGYESI, D. W. COBLE, F. S. FANG, and E. O. KAIRINEN, *Gillette Research Institute, 1413 Research Boulevard, Rockville, MD 20850.*

Received June 24, 1983. Presented at the Society of Cosmetic Chemists Annual Scientific Meeting, New York, New York, December 6-7, 1979.

Synopsis

A study was conducted to elucidate the differences in morphology, physical properties, chemical composition, and reactivity between facial hair and scalp hair, utilizing light and electron microscopy, tensile measurements, amino acid analyses, and reaction rates. The effect of ethnic background on fiber structure and geometry was also investigated. The beard and scalp hairs of all three ethnic groups (Caucasian, Chinese, and Negro) differed significantly in fiber morphology. Scalp fibers had smaller cross-sectional areas and were more rounded than beard fibers, which exhibited asymmetrical, oblong, and trilobal shapes. There were more cuticle layers, less ordered scale patterns, and more extensive medullation in beard hair than in scalp hair of the same subject. In addition, some ethnic differences were observed in fiber size, geometry, and pigmentation in both facial and scalp hair.

The principal difference in chemical composition was the lower disulfide content of beard hair. In addition, beard hair was richer in aspartic acid, lysine, and tyrosine and poorer in valine and serine. The higher disulfide content of scalp hair was reflected in greater resistance to solubilization by urea-bisulfite, slower swelling rate in formic acid, and less supercontraction or permanent set in bisulfite solutions than beard hair under identical conditions.

INTRODUCTION

The structure and physico-chemical properties of human hair are of great interest in relation to cosmetic processes applied to them. During the past twenty years, with the availability of electron microscopy and modern chromatographic techniques, great progress has been made in the characterization of the morphology (1-7), chemical composition and reactivity (8-12) of human scalp hair, and understanding effects of racial background on these properties (4-5, 12-14). Unfortunately, very few corresponding data are available about beard hair (14-17). A study was therefore conducted to elucidate differences in morphology, physical properties, chemical composition and reactivity between facial hair and scalp hair, utilizing, when possible, the beard and scalp fibers of the same individual and examining the hair of three racial groups: Caucasian, Chinese, and Negro.

MATERIALS AND METHODS

1. *Reagents*

All the chemcial reagents were Certified ACS Grade or higher purity.

2. *Hair Sample Acquisition*

Samples of beard and scalp hair for microscopy and tensile determinations were collected from men (10 Caucasians, 6 Chinese, and 6 Blacks) who were 20 to 50 years old. The fibers were cut very close to the skin line; beard hair was taken from the lower chin area and scalp hair from the rear crown of the head.

For chemical characterizations the hair fibers of several individuals were pooled; beards were contributed by ten Caucasian men and Caucasian scalp hair was purchased from DeMeo Brothers, New York.

3. *Hair Sample Preparation*

a. *Purification*

Specimens for microscopy and tensile work were purified by a half-hour immersion in 1% aqueous Triton® X-100 followed by repeated distilled water rinses and a half-hour immersion in ethanol. The fibers were then air dried at room temperature.

Bulk hair samples (50 g batch) were purified via Soxhlet extractions with anhydrous ether (14 hours) and ethanol (7 hours). The hair was then air dried, immersed in 0.001 N HCl (2 hours), and rinsed repeatedly with large volumes of distilled water until the pH of the overnight rinse water was 5.0.

b. *Mounting of Hair Fibers*

The fibers were individually mounted either with double-coated transparent tape onto microscope slides or in glycerin on slides under a coverslip.

c. *Cross Sections of Fibers*

Cross sections of fibers (6-8 μm thick) were cut with the Hardy Microtome and mounted in glycerin under a coverslip on microscope slides.

4. *Light Microscopy*

An American Optical Microstar® Series 10 Microscope, equipped with a Polaroid® Land Camera, or Zeiss® Microscope Model 62119 with 10× and 40× polarizing objectives was used in determinations of the diameter, ellipticity, and cross-sectional area of hair fibers.

a. *Measurement of Fiber Diameter*

A specially constructed microscope stage was used which would accommodate tabbed single fibers which could be rotated 180° along the long axis of the fibers.

Five beard and five scalp hair fibers from each of ten individuals were investigated. Fibers were examined at five sites along each sample. At each site, fibers were rotated

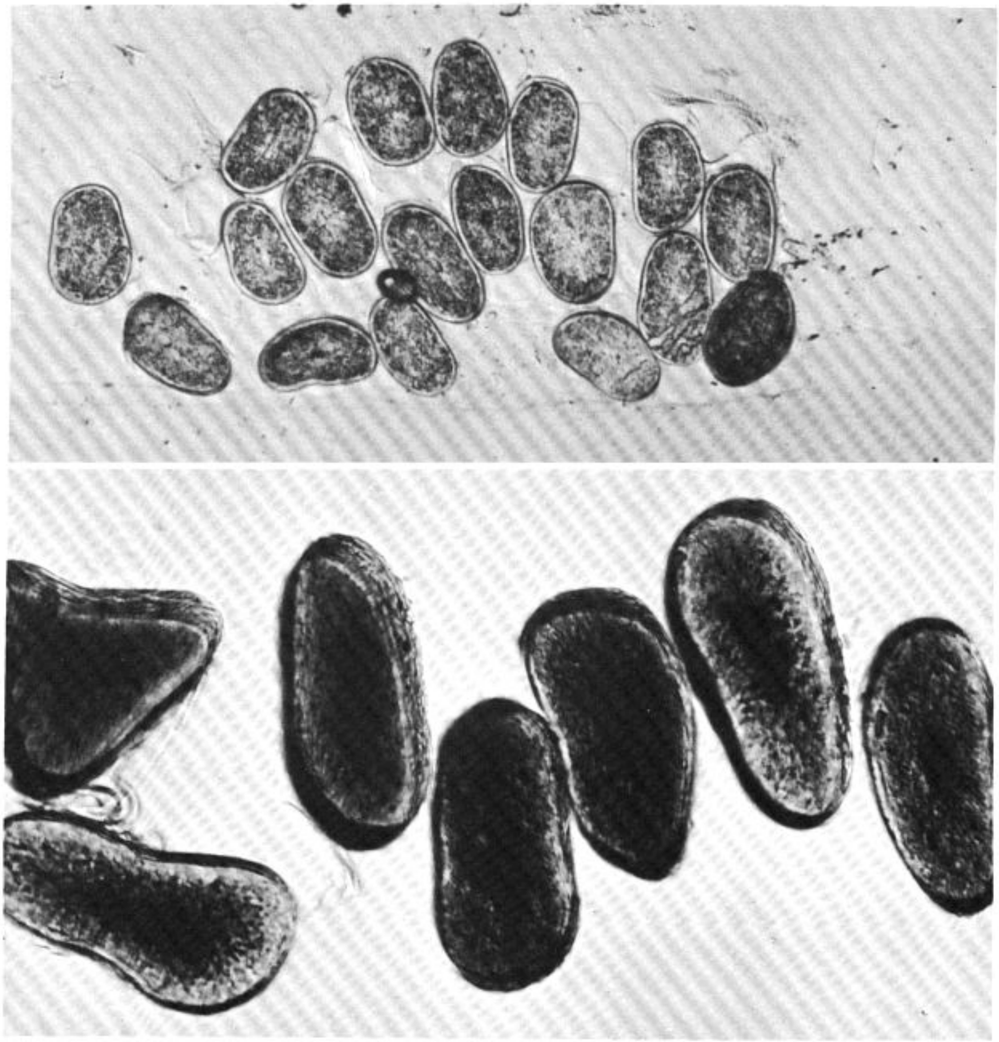

Figure 1. Polarized light photomicrographs of Caucasian scalp hair (top) and beard hair (bottom) cross-sections of the same subject. Magnification 150×.

and measurements taken at 0°, 45°, 90°, 135°, and 180°. The averages of the measurements, taken at all five angles, for all five sites, for each fiber, were then calculated. Data presented are averages for all five fibers for each subject, and the standard deviation from fiber to fiber is reported.

b. *Determination of Fiber Ellipticity*

i. *Direct Measurement*

Using the data obtained in 4a. above, ellipticity indices, that is, the ratios of fiber major axes over fiber minor axes, were obtained.

ii. *Indirect Measurement*

From the photographs of the cross-sections, the major axis (longest "diameter") was selected, and the minor axis was the line bisecting the major axis.

$$\text{Ellipticity Index} = \frac{\text{Major Axis}}{\text{Minor Axis}}$$

For each beard or scalp hair sample type at least twelve cross-sections were prepared (six fibers each from two individuals) for this purpose.

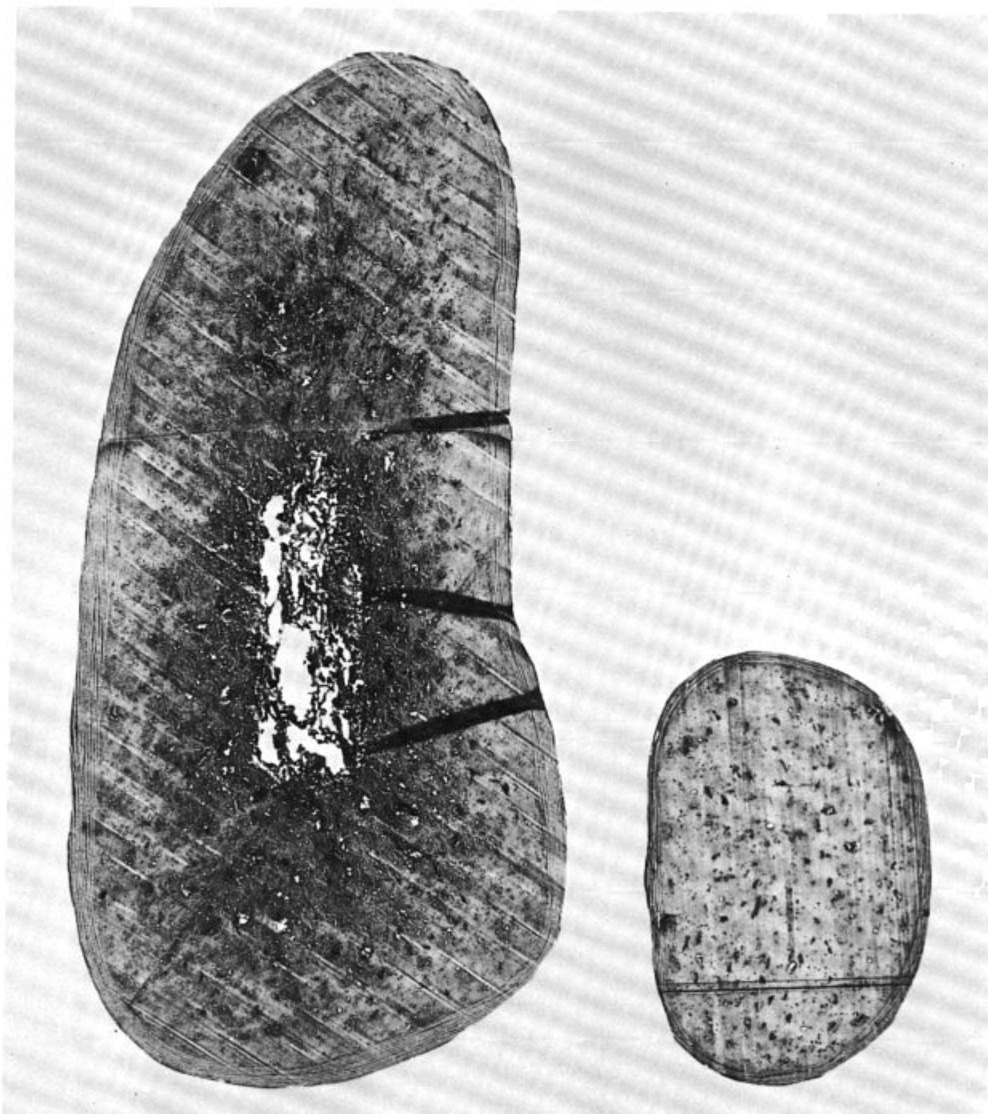

Figure 2. Transmission electron micrographs of Caucasian beard and scalp hair cross-sections of the same subject. Magnification 915×.

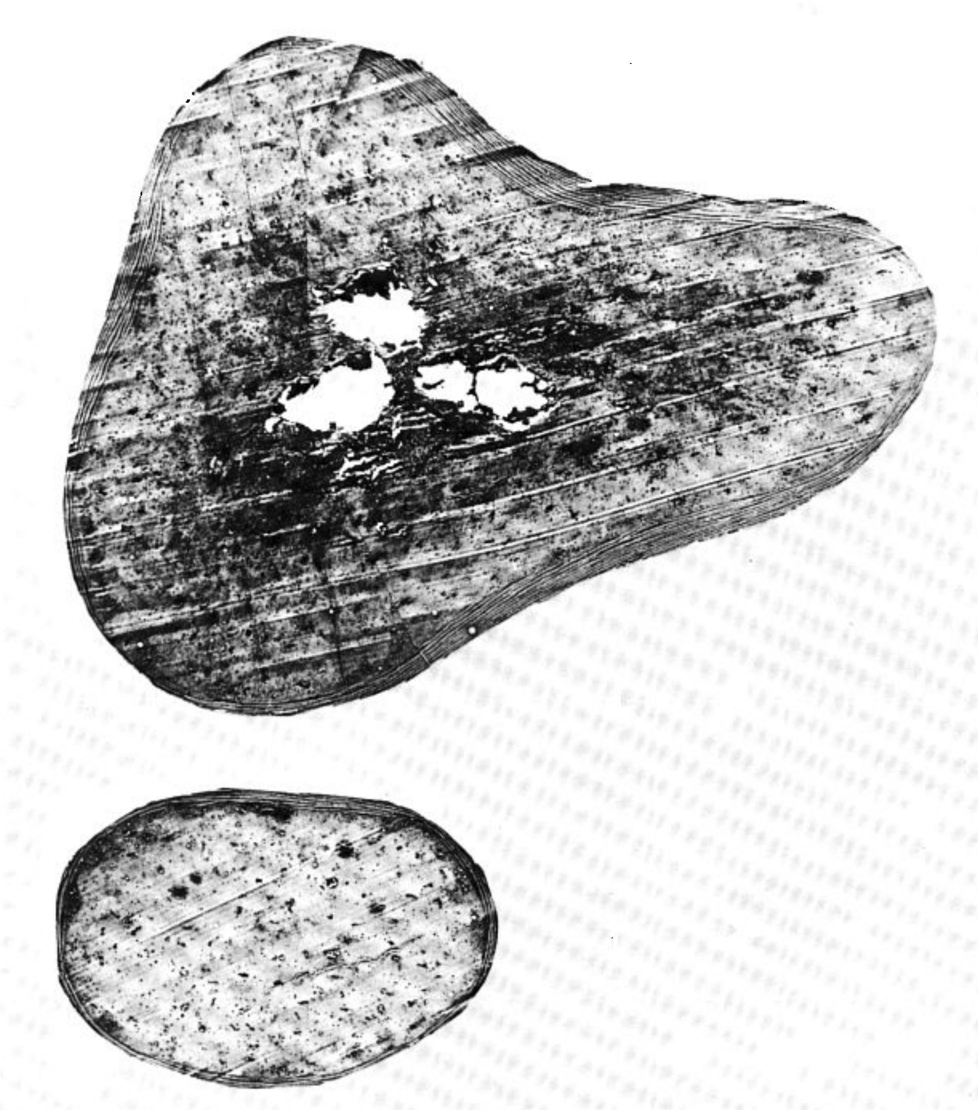

Figure 3. Transmission electron micrographs of Caucasian beard and scalp hair cross-sections of the same subject. Magnification 915×.

c. *Cross-Sectional Area Measurement*

Cross-sections of hair fibers, magnified 300× on photographs, were traced with a planimeter for area determination. For each beard or scalp hair type, measurements of at least 12 cross-sections were taken (six fibers each from two individuals).

5. *Transmission Electron Microscopy (TEM)*

Intact scalp and beard hairs were placed in flat silicon rubber molds and embedded in Durcupan® Fluka Epoxy resin at 60°C. Prior to embedment, the hairs were oriented for

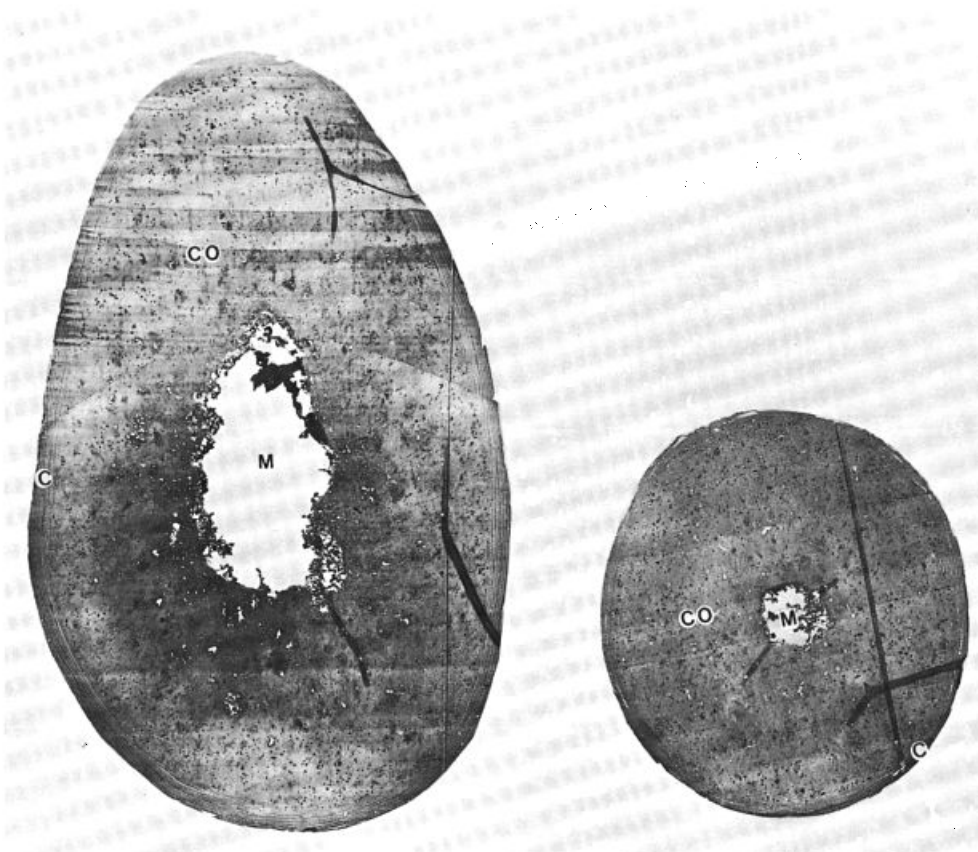

Figure 4. Transmission electron micrographs of Chinese beard and scalp hair cross-sections of the same subject. Magnification 915×. M: Medula; CO: Cortex; C: Cuticle.

Table I
Diameters of Caucasian Beard and Scalp Hair

Subject	Diameter[a] (μm) Beard Hair	Scalp Hair	Beard/Scalp
CMT	143.7 ± 6.9	72.0 ± 2.9	2.00
DLS	124.6 ± 8.7	79.9 ± 1.1	1.56
GHS	131.3 ± 3.2	72.9 ± 1.7	1.80
JGY	123.3 ± 5.7	71.4 ± 15.1	1.73
LHE	107.0 ± 3.3	64.3 ± 4.6	1.66
MDG	126.9 ± 11.3	58.7 ± 7.6	2.16
NHS	120.8 ± 11.3	55.7 ± 2.9	2.17
PHY	113.4 ± 5.6	68.9 ± 8.9	1.65
PKA	139.1 ± 20.8	86.6 ± 4.5	1.61
SDN	125.6 ± 13.1	65.3 ± 11.0	1.92
Average	125.6 ± 10.9	69.6 ± 9.3	1.83

[a]Five beard and five scalp hairs from each subject were measured at five locations along the fiber. At each location the fiber was rotated and measurements taken at 0°, 45°, 90°, 135°, and 180° axial rotation. Diameter values for the five fibers were averaged and reported here along with standard deviations from fiber to fiber.

either cross or longitudinal sectioning, beginning at the proximal end. Serial sections, 600 Å thick, were cut with a diamond knife in a Sorvall® Porter Blum MT-2 ultramicrotome. The sections were placed on carbon-backed nitrocellulose-covered single slot copper grids and stained with lead citrate/uranyl acetate for image enhancement. The TEM studies were performed on a J.E.O.L. Model 100 B at 80 kV.

6. *Scanning Electron Microscopy (SEM)*

Small segments of hair fibers, 5-8 mm in length, were mounted with double-coated transparent tape onto SEM specimen holders. The mounted samples were coated with approximately 30 nm gold in a Polaron Instruments E5100 Sputter Coater and examined at 60° tilt in a J.E.O.L. Model JSM-U2 Scanning Electron Microscope, operated at 6, 9, 15, or 24 kV. Micrographs of each fiber were made at 300× to 10,000× magnifications.

7. *Tensile Measurements*

Tensile properties were determined on an Instron Tension Compression Tester Model TT-D, extending 5 cm long fiber specimens, of 70–90 μm diameter, in water at 1 cm/min. A Perkin Elmer Autobalance® Model AD-2 was used to establish the linear density of the fibers. For each sample 20 fibers (ten fibers each from two subjects) were tested.

8. *Amino Acid Analysis*

Acid hydrolysates of the hair samples were analyzed on a Beckman® Model 119 Automatic Amino Acid Analyzer.

9. *Urea-Bisulfite Solubility Test*

Standard test method I.W.T.O.-11-54 (18) was used to determine urea-bisulfite solubility. Triplicate analyses were performed.

Table II
Ellipticity Indices of Caucasian Beard and Scalp Fibers

	Ellipticity Index[a]	
Subject	Beard Hair[b]	Scalp Hair[b]
CMT	2.08 ± 0.18	1.42 ± 0.21
DLS	1.72 ± 0.50	1.58 ± 0.20
GHS	1.55 ± 0.27	1.41 ± 0.05
JGY	1.81 ± 0.32	1.35 ± 0.19
LHE	1.55 ± 0.18	1.48 ± 0.12
MDG	1.97 ± 0.23	1.44 ± 0.07
NHS	1.58 ± 0.27	1.20 ± 0.11
PHY	1.83 ± 0.13	1.27 ± 0.17
PKA	1.80 ± 0.15	1.74 ± 0.22
SDN	1.35 ± 0.24	1.46 ± 0.22
Average	1.72 ± 0.20	1.44 ± 0.15

[a]Ratio of the major axis to the minor axis.
[b]Diameters of five beard and five scalp fibers were measured at five locations along the fiber and five axial rotations at each location. Average values and standard deviations are reported.

10. *Swelling in Formic Acid*

Volume swelling of beard and scalp hair fibers in 97% formic acid was determined according to Caldwell and Milligan (19). The diametral swelling of beard and scalp fibers of comparable diameters was measured on microbiological culture slides, in 97% formic acid, under a coverslip, at one minute intervals, in the view of the light microscope.

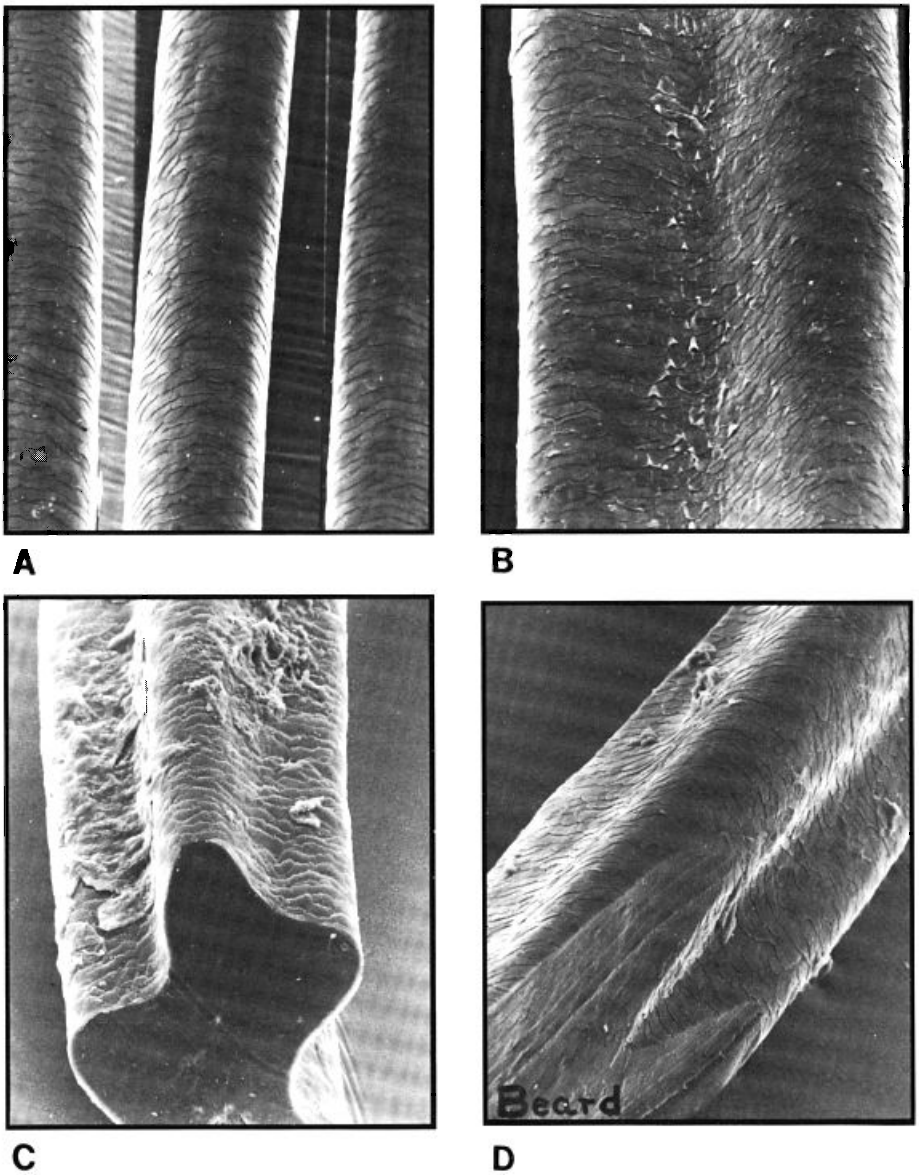

Figure 5. Scanning electron micrographs of typical Caucasian scalp hairs (A) and beard hairs (B, C, D). Magnification 300×.

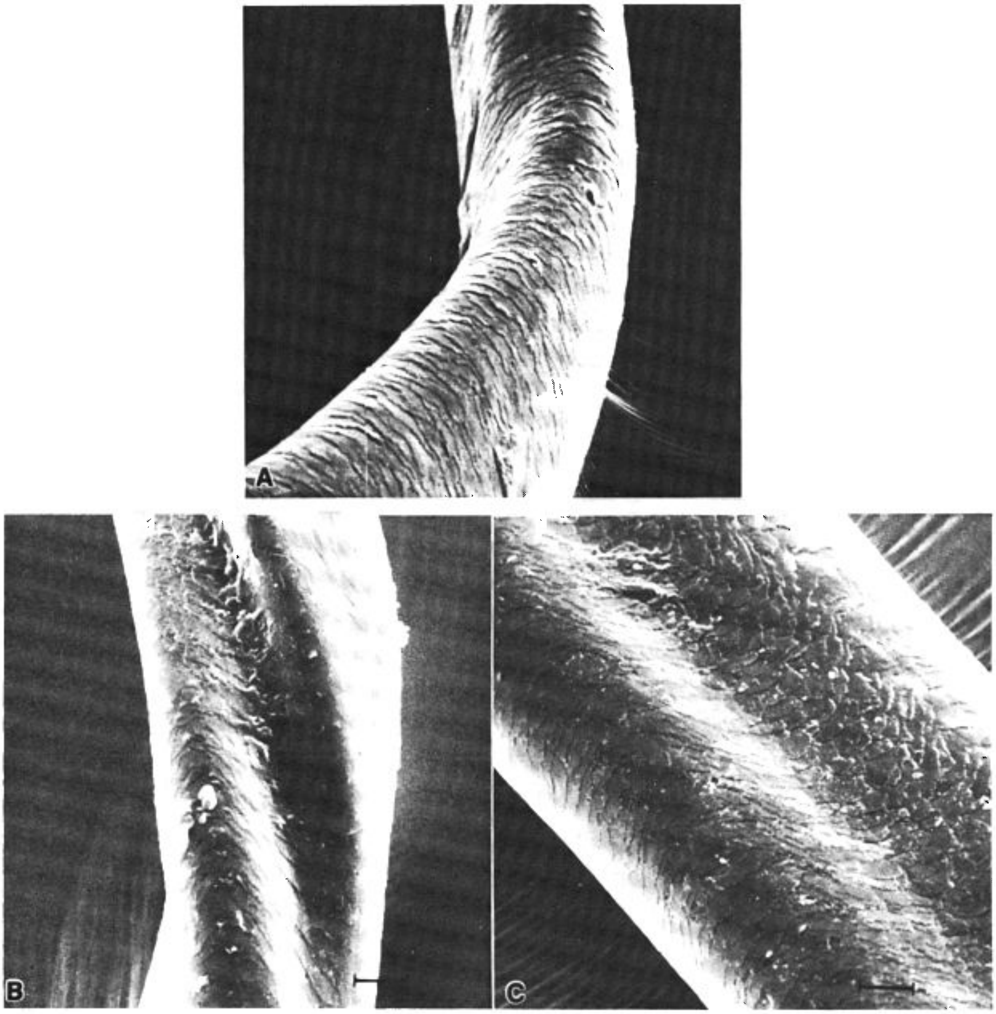

Figure 6. Scanning electron micrographs of typical Negro scalp (A) and beard hairs (B, C). Magnification 600×.

11. *Permanent Set*

The percent set imparted to scalp and facial hair fibers of similar diameters, when treated at 30% extension in boiling 5% sodium bisulfite for 30 minutes, followed by 30 minute relaxation in boiling distilled water, was determined. At least four fibers per sample were analyzed and the values averaged.

12. *Supercontraction*

The contraction of hair fibers, when treated in the relaxed state, at the boil, for 30 minutes with 5% sodium bisulfite, followed by 30 minute relaxation in distilled water at room temperature and air drying, was calculated. Four fibers per sample were analyzed.

RESULTS AND DISCUSSION

1. *Fiber Morphology*

Light and transmission electron microscopy studies showed that scalp fibers had significantly smaller cross-sectional areas and were generally circular-elliptical, whereas facial hairs were asymmetrical, in the oblong, kidney, and trilobal configurations (Figures 1–4).

In the ten Caucasian individuals, the diameter of beard hair was larger than that of scalp hair (Table I, Figures 2–4). It has to be noted, however, that there was a considerable variation in cross-sectional size and shape along the hair fiber, among fibers from the same individual, and among fibers from individuals within the same race. The variation can be illustrated by the range of average diameters and ellipticity indices (Tables I–II). Differences were larger in beard then in scalp hair.

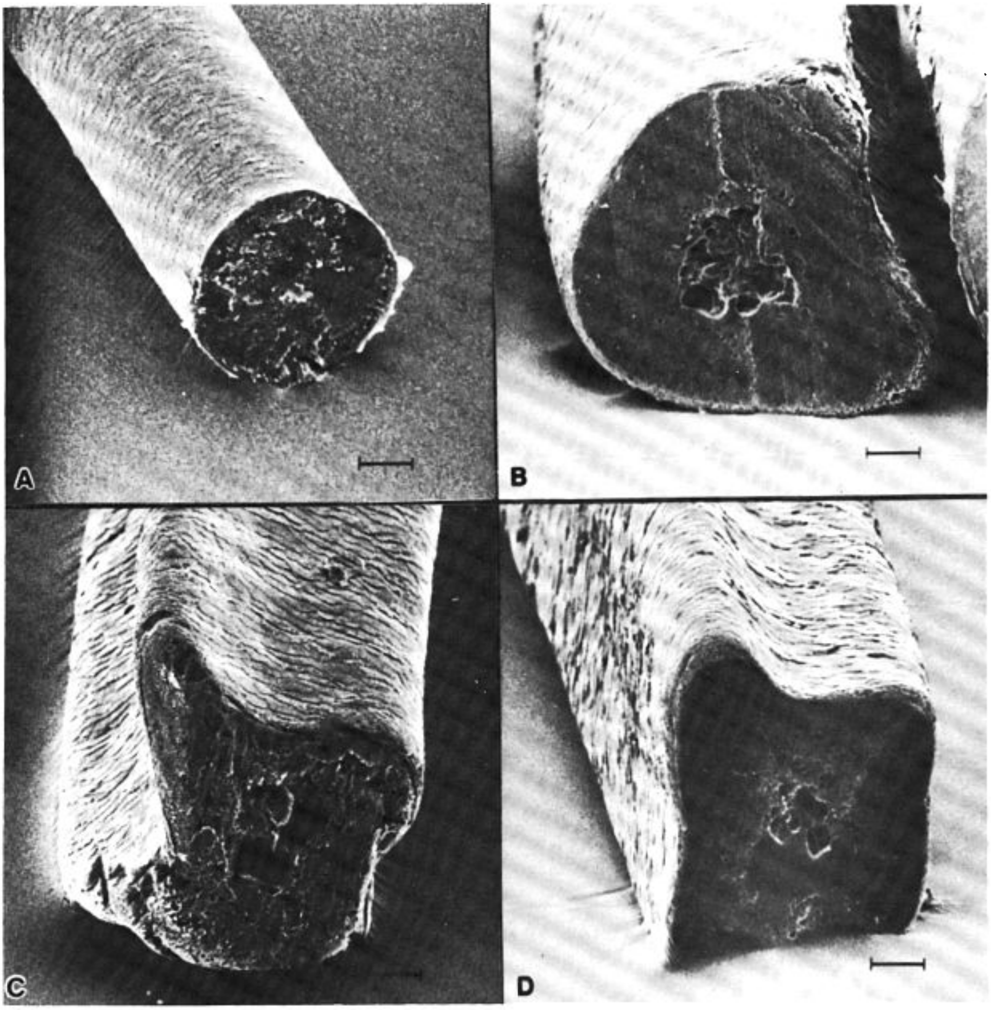

Figure 7. Scanning electron micrographs of typical Chinese scalp hair (A) and beard hairs (B, C, D). Magnification 400×.

Table III
Characterization of Scalp and Beard Hair of Three Racial Groups

Fiber Type[a]	Cross-sectional Area[b] (μm^2)	Major Axis (μm)	Minor Axis (μm)	Ellipticity Index[c]
Caucasian				
Scalp	6,300 ± 1000	110.8 ± 11.0	67.8 ± 23.8	1.6 ± 0.3
Beard	10,700 ± 1400	164.4 ± 14.1	79.7 ± 16.8	2.1 ± 0.5
Chinese				
Scalp	7,600 ± 2300	106.4 ± 18.3	82.8 ± 10.2	1.3 ± 0.2
Beard	14,100 ± 3900	171.3 ± 29.3	94.4 ± 24.1	1.9 ± 0.5
Negro				
Scalp	6,200 ± 1200	118.8 ± 15.2	66.1 ± 15.1	1.9 ± 0.4
Beard	12,900 ± 4400	172.7 ± 31.1	84.6 ± 20.2	2.1 ± 0.4

[a]For each hair type twelve cross-sections were prepared, six fibers each from two individuals.
[b]Indirect measurement from photographs using planimeter.
[c]Ratio of the major axis to the minor axis.

Scanning electron microscopy studies also confirmed the differences in fiber size and shape between beard and scalp hair in all three racial groups. Representative scanning electron micrographs are shown in Figures 5-7. Caucasian scalp hairs were round or oval in cross-section, while the beard hairs usually had more asymmetric shapes. Negro scalp and facial hair fibers had twisted ribbon shapes which in cross-section appeared as flattened or curved ovals. Sharp twists along the fiber axis produced kinky hairs. Chinese scalp hairs were straight and regular, with circular or slightly oval cross-sections; the beard hairs, however, showed the widest range of shapes. Measuring the cross-sectional areas and ellipticity via optical microscopy, the cross-sectional area of beard hair was found to be 70–100% greater in all three racial groups than that of the corresponding scalp fibers (Table III). Beard fibers were more irregular in shape than the scalp fibers, giving larger ellipticity indices. Due to the variability among the hair fibers from each individual and among the individuals within each race, significant racial differences in the quantitation of size and shape of beard hair or scalp hair were not obtained from the limited data of this study. However, a trend emerged, showing that Chinese beard and scalp hairs were coarser and the cross-sections more circular than the corresponding fibers of Caucasian or Negro origins.

Comparing the number of cuticle layers in beard and scalp hair samples, it was observed that there were nearly twice as many in facial hair as in the scalp fibers of the

Table IV
Number of Cuticle Layers in Beard and Scalp Hair[a]

Fiber Type	Beard Hair	Scalp Hair	Beard/Scalp
Caucasian[b]	10.3 ± 1.6	6.4 ± 1.4	1.7 ± 0.4
Black[c]	8.3 ± 2.1	5.3 ± 1.5	1.7 ± 0.8
Chinese[c]	11.5 ± 1.9	6.3 ± 1.2	1.8 ± 0.2

[a]Determined from transmission electron micrographs.
[b]Five fibers each from six subjects; four cross-sections per fiber.
[c]Five fibers each from four subjects; four cross-sections per fiber.
Average values and standard deviations are reported.

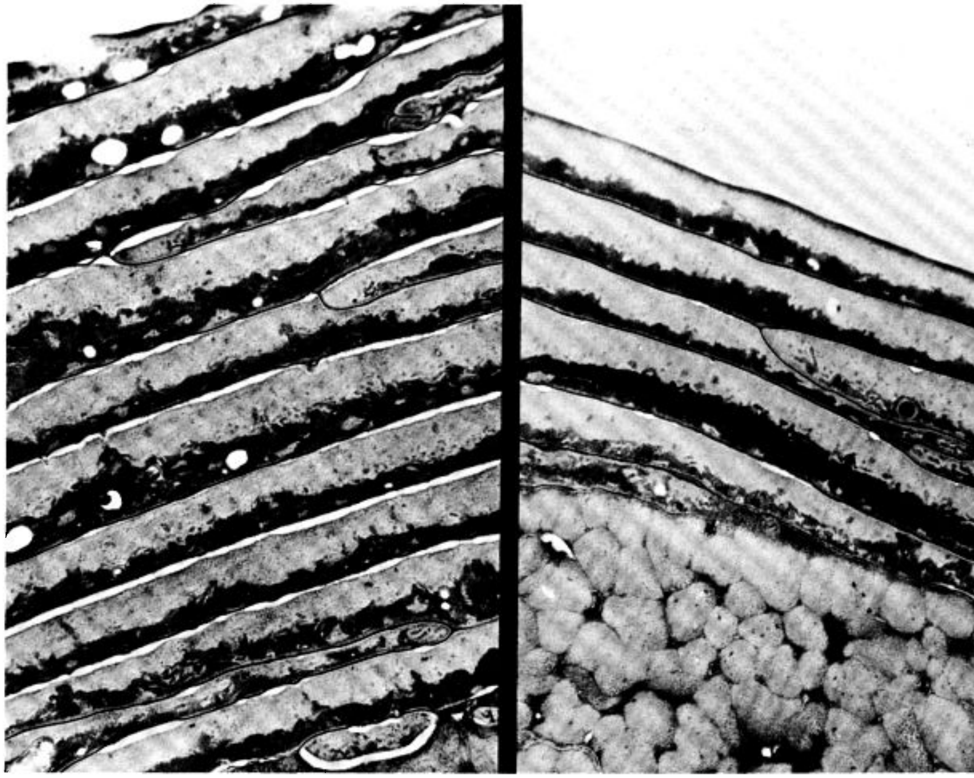

Figure 8. Transmission electron micrographs of Caucasian beard (left) and scalp hair (right) cuticle cross-sections. Magnification 36,600×.

same subject (Table IV, Figure 8). The thickness of individual cuticle cells was about 0.5 μm in both cases. While the gross surface structure appeared to be similar in facial and scalp hair, larger areas of the cuticle cells were exposed and the scale pattern was more ordered on scalp fibers (Figure 9). Cylindrical fibers and the convex portions of flattened or irregular fibers had wider, more oblong shaped cuticle cells. Distal edges of cuticle scales on beard hairs were often less chipped than on the corresponding scalp hairs. This was probably due to less mechanical damage having been inflicted by grooming practices on the beard than on the scalp hairs. On scalp hairs within a few millimeters of the skin line this scale edge damage was not apparent.

Longitudinal sections of beard hair, examined in the TEM or under polarized light, usually revealed a continuous or discontinuous medulla, representing material joined by a filamentous network parallel to the long axis of the fiber (Figures 10, 12). By comparison, scalp hairs were much less extensively medullated. However, even scalp or facial hairs from the same individual showed significant variation in medullation. The studies also demonstrated, particularly in beard hairs, that the melanin pigment granules appeared not only in the cortical cells, as commonly reported in the literature, but also in the cuticle and medulla (Figures 13–14), especially in heavily pigmented Chinese hair (Figure 15) or Negro hair.

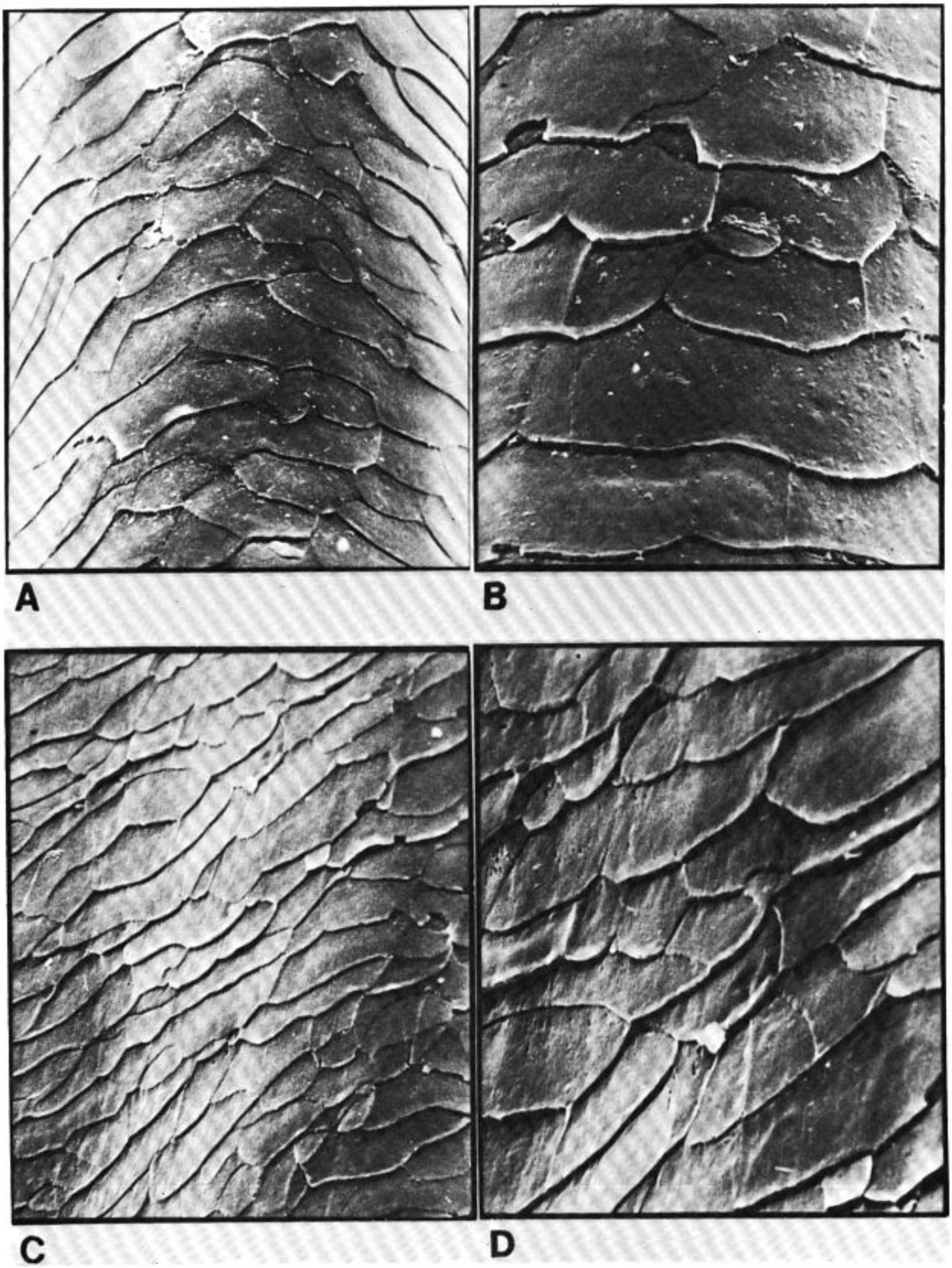

Figure 9. Comparison of the cuticular patterns of Caucasian scalp hairs (A, B) and beard hairs (C, D). Magnifications 1000× (A, C) and 2000× (B, D).

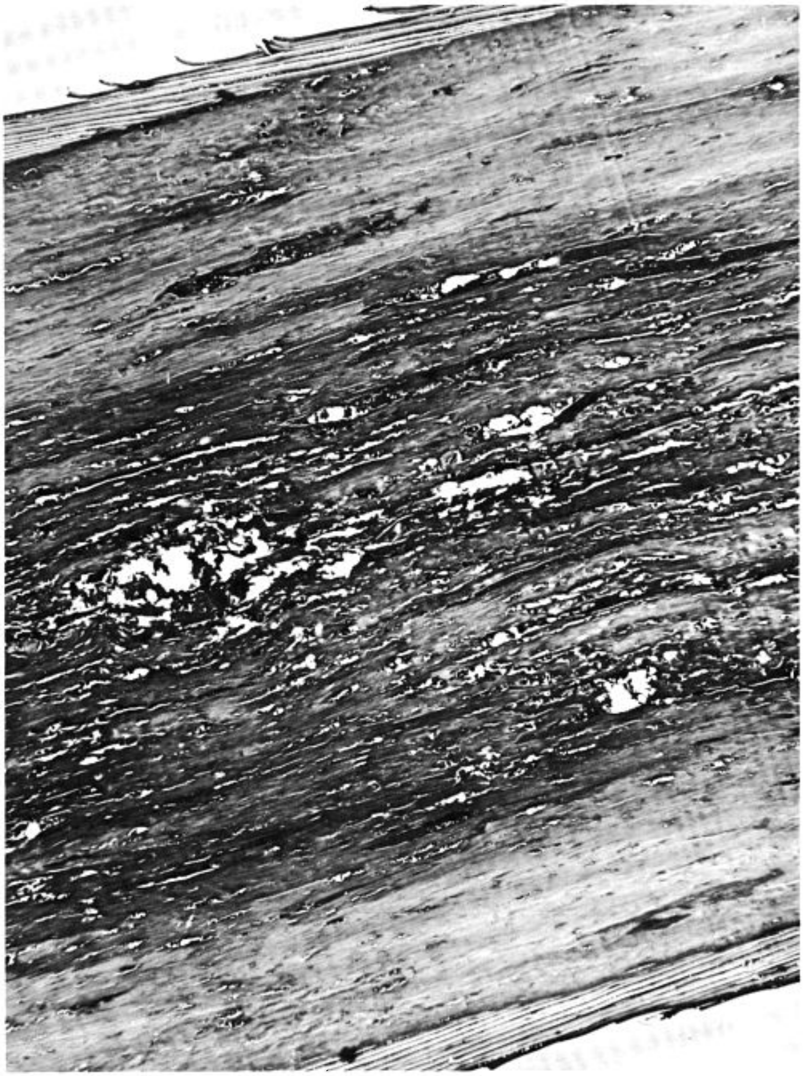

Figure 10. Transmission electron micrograph of longitudinal section of Caucasian beard hair. Magnification 2750×.

2. *Mechanical Properties*

The tensile properties of Caucasian beard and scalp hair in water, at 21°C, are summarized in Table V. The lower elastic modulus of beard is probably due to both the lower level of disulfide bonding (as shown later in this paper) and the higher degree of medullation.

3. *Chemical Characterization*

a. *Amino Acid Composition*

The amino acid profiles of Caucasian facial and scalp hair (Table VI) showed a significant difference in the cystine content, which was about 18% lower in beard hair.

This result was somewhat unexpected, considering the fact that beard hair has more cuticular layers which are rich in cystine (5). The overriding factor is presumably the relatively high level of medullation in beard hair, since medullary cells were shown to have very little cystine but higher levels of basic, acidic, and aromatic amino acids (20–21). It is, however, also possible that the cystine level of the cortical cells of facial and scalp hair is different.

Beard hair was also found to be richer in aspartic acid, lysine, and tyrosine and poorer in threonine, serine, and valine.

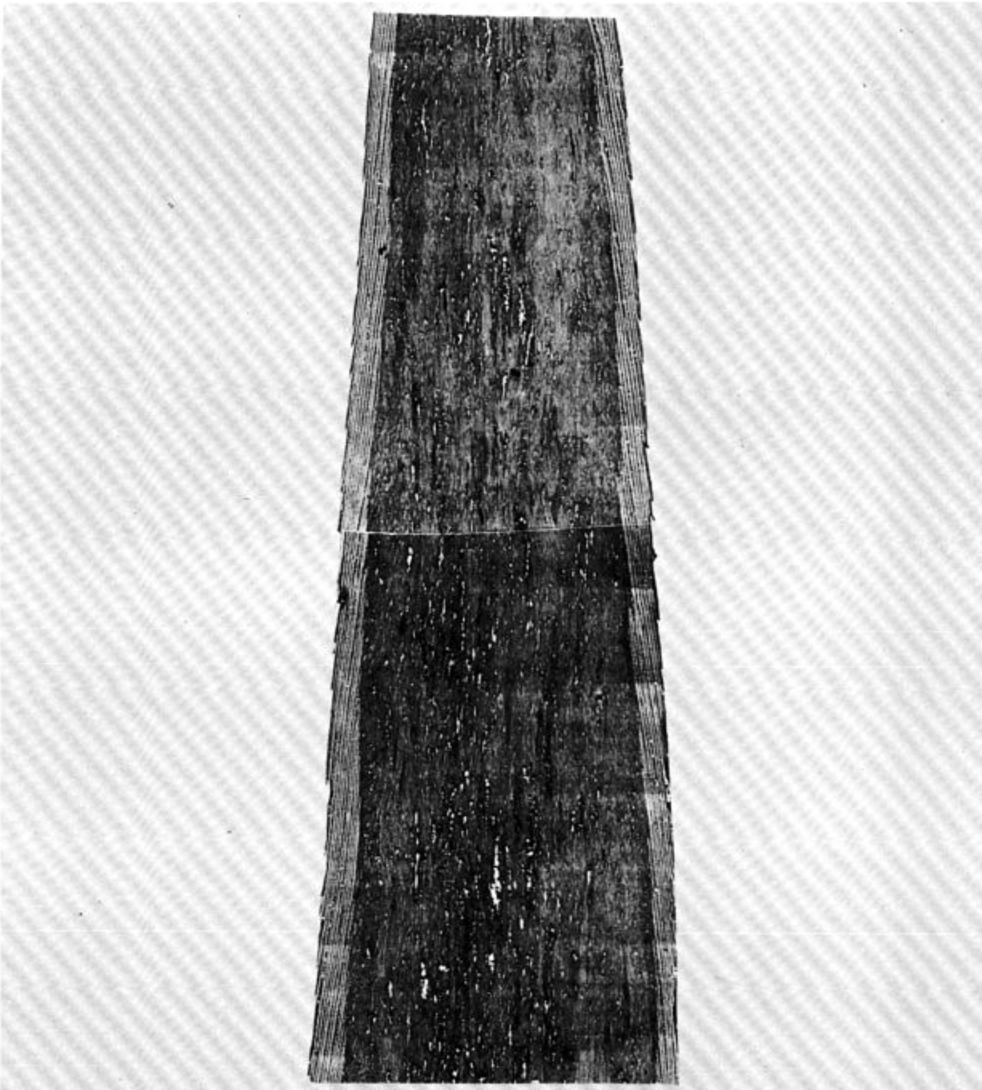

Figure 11. Transmission electron micrograph of longitudinal section of Caucasian beard hair without medullation. Magnification 915×.

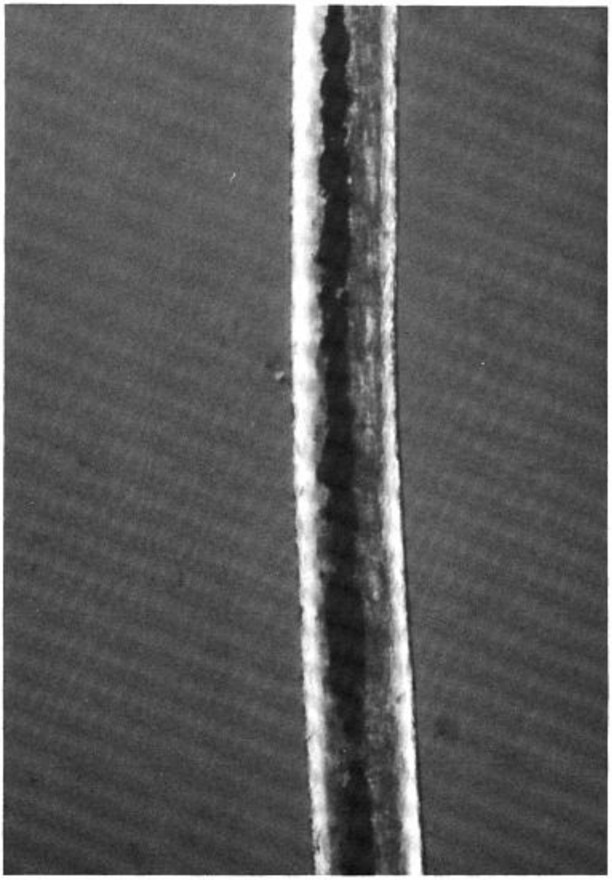

Figure 12. Polarized light photomicrograph of beard hair with an intermittent medulla. Magnification 150×.

b. *Solubility in Urea-Bisulfite Solution*

The solubility of wool in urea-bisulfite solution, under standard conditions (18), is a test used in the wool industry that provides an index of the extent of change in the fiber's chemical properties, resulting from certain processing steps. The formation of new cross-links leads to decrease in solubility, whereas degradative treatments result in an increase.

Table V

Tensile Properties of Caucasian Beard and Scalp Hair in Water at 21°C

Property	Beard Hair[a]	Scalp Hair[a]
Initial Modulus, dynes/cm^2	$(1.18 \pm 0.22) \times 10^{10}$	$(1.55 \pm 0.13) \times 10^{10}$
Stress at Yield Point, dynes/cm^2	$(3.57 \pm 0.51) \times 10^{8}$	$(4.31 \pm 0.21) \times 10^{8}$
Stress at 20% Extension, dynes/cm^2	$(4.47 \pm 0.53) \times 10^{8}$	$(5.18 \pm 0.42) \times 10^{8}$
Post Yield Modulus, dynes/cm^2	$(3.60 \pm 0.80) \times 10^{9}$	$(4.92 \pm 0.42) \times 10^{9}$
Extension to Post Yield, (%)	26.2 ± 1.4	25.1 ± 0.7

[a]For each fiber type twenty fibers, ten fibers each from two subjects, were tested. Average values with standard deviations are reported.

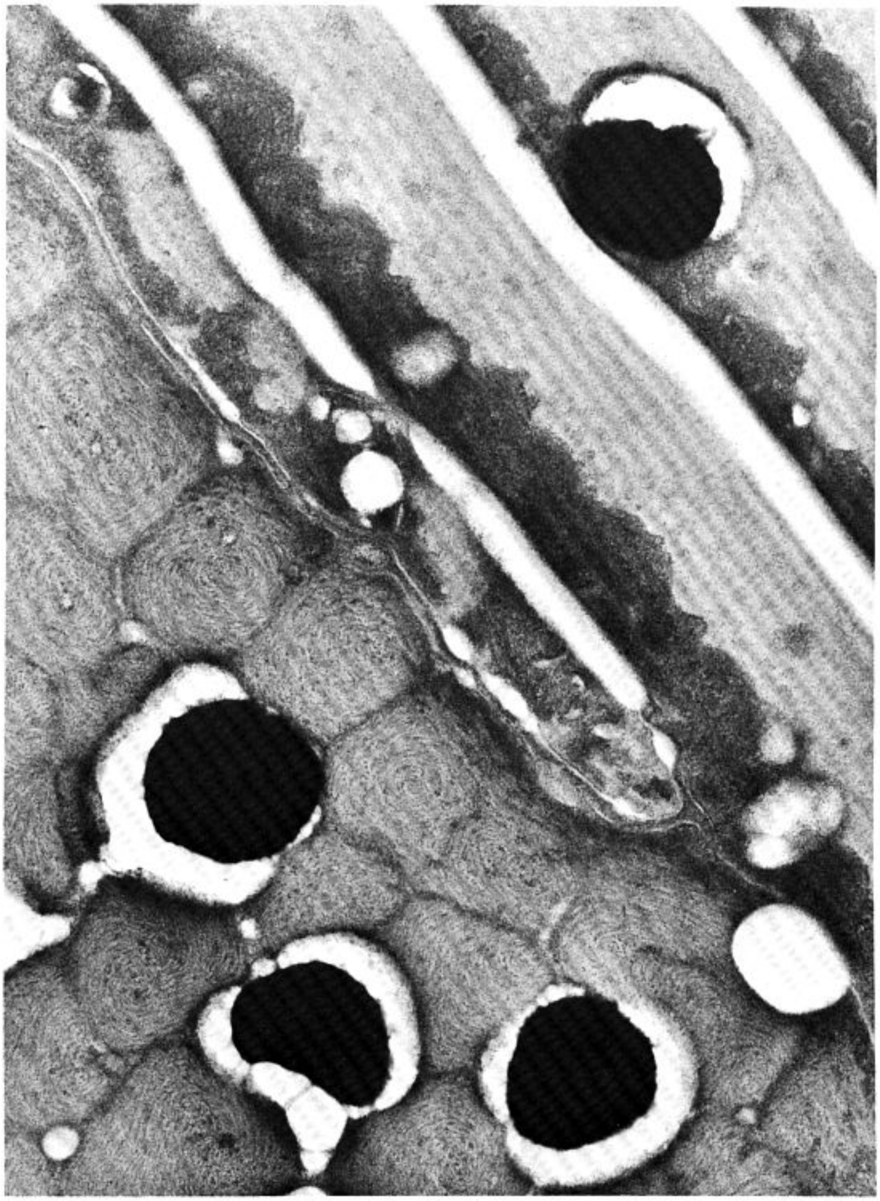

Figure 13. Transmission electron micrograph of Caucasian scalp hair cross-section showing melanin in cuticle and cortex. Magnification 91,600×.

The much faster rate of solubilization of Caucasian beard hair, as compared to scalp hair, in urea-bisulfite (Figure 16) is in good agreement with the lower disulfide content of facial hair.

c. *Swelling Studies in Formic Acid*

Caldwell and Milligan (19) developed a gravimetric method for measuring the extent of swelling of wool in concentrated formic acid and correlating the swelling data with the

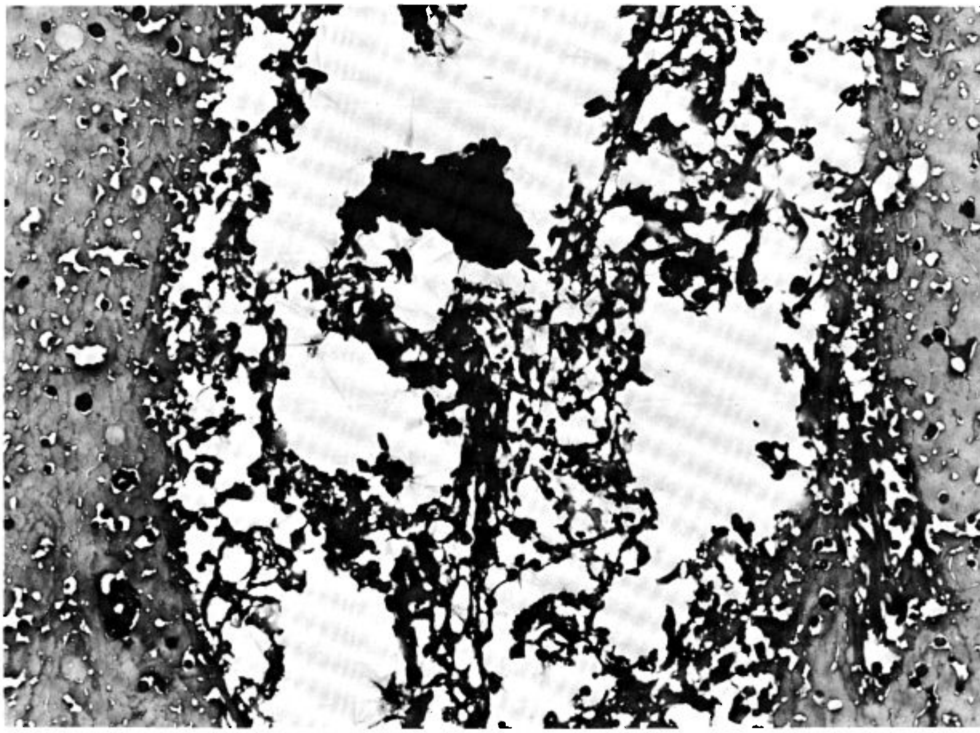

Figure 14. Transmission electron micrograph of Caucasian beard hair cross-section showing melanin in medulla. Magnification 9160×.

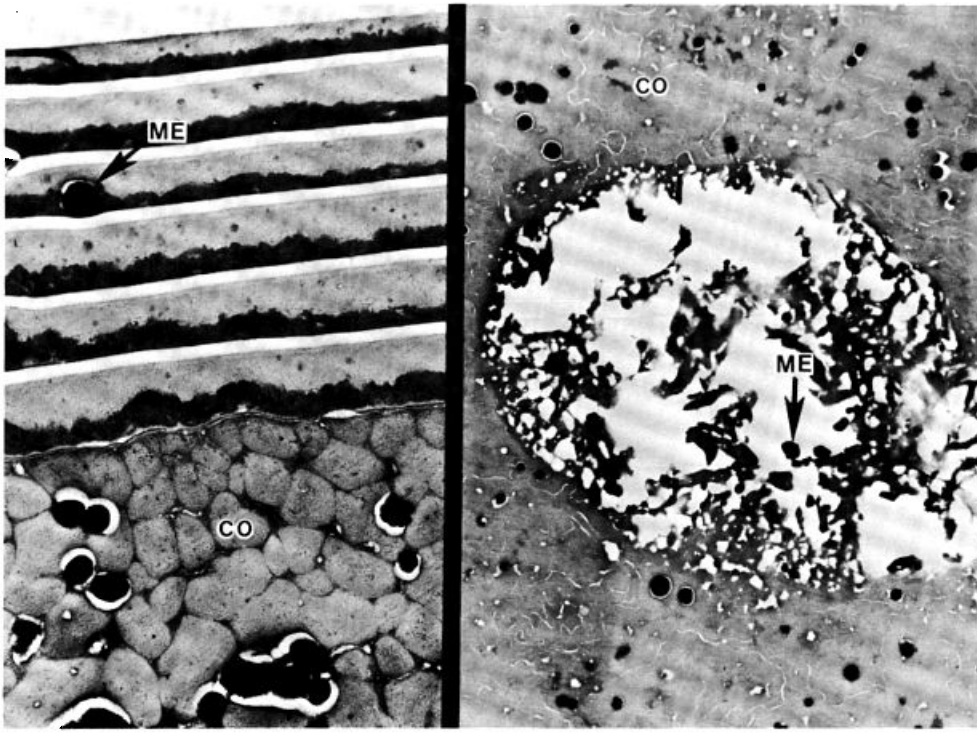

Figure 15. Transmission electron micrographs showing melanin in the cuticle, cortex and medulla of Chinese scalp hair. ME: Melanin; CO: Cortex.

Table VI
Amino Acid Contents of Caucasian Scalp Hair and Beard Hair (micromoles/g)

Type of Amino Acid	Scalp Hair[a]	Beard Hair[b]
Cysteic Acid	30	19
Aspartic Acid	431	463
Threonine	539	484
Serine	1,121	971
Glutamic Acid	997	964
Proline	615	634
Glycine	448	452
Alanine	345	354
Half Cystine	1,170	963
Valine	363	322
Methionine	31	30
Isoleucine	152	162
Leucine	456	468
Tyrosine	112	128
Phenylalanine	90	98
Lysine	247	285
Histidine	56	60
NH_3	797	777
Arginine	586	552

[a]Bulk hair from De Meo Brothers.
[b]Bulk hair from ten subjects.
Duplicate evaluations, variations about ±10%.

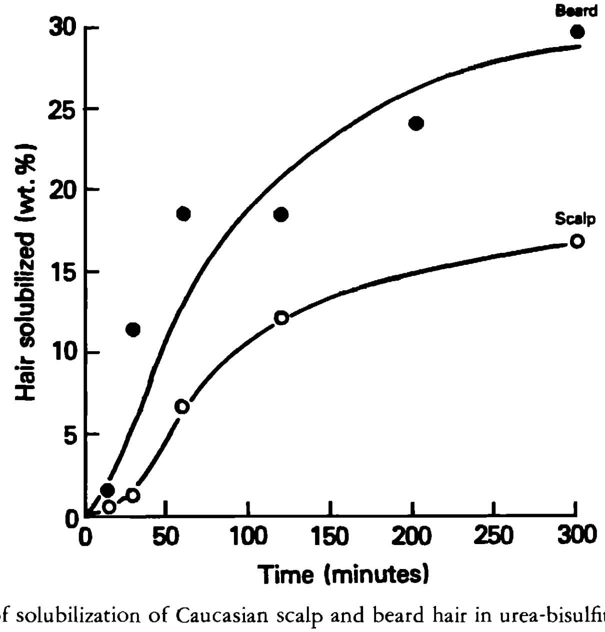

Figure 16. Rate of solubilization of Caucasian scalp and beard hair in urea-bisulfite solution. Triplicate analysis on bulk hair.

relative number of randomly distributed disulfide bonds in the fiber. This technique was used to determine the comparative swelling rates of beard and scalp hair.

In 97% formic acid the volume swelling (V_H) of Caucasian beard and scalp hair was determined to be 0.41 ± 0.02 and 0.44 ± 0.02, respectively. Since V_H was defined as the volume of dry hair expressed as a fraction of the volume of swollen hair, the lower volume swelling index for beard hair indicates a higher degree of swelling and thus a lower degree of disulfide bonding.

In good agreement with the above studies, Caucasian beard fibers exhibited a faster rate as well as a higher degree of swelling in 97% formic acid, than scalp hair of similar diameter (Figure 17).

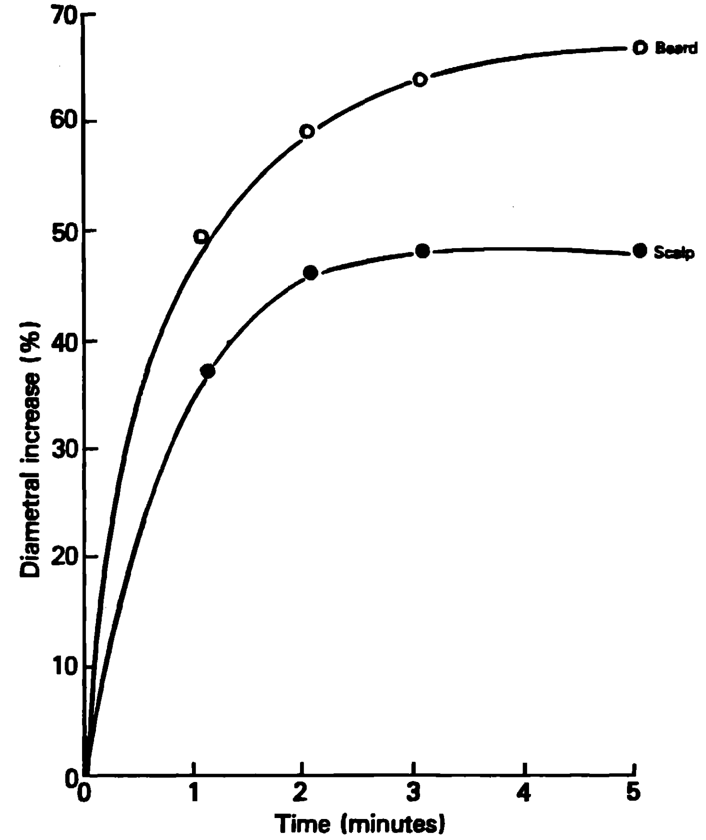

Figure 17. Diametral swelling of Caucasian beard and scalp hair in 97% formic acid solution. Each data point is the average of measurements from five fibers for each of five subjects (25 samples).

d. *Permanent Set and Supercontraction*

Supercontraction and set are characteristics of keratin fibers in certain media (22), and their level is principally dependent on the chemical composition of the cortical regions of the fibers (23). As fiber thickness is another parameter influencing the level of set incurred (23), facial and scalp hairs of similar diameters were selected for this study.

Table VII
Permanent Set and Supercontraction of Caucasian Beard and Scalp Hair

Property	Beard Hair[a]	Scalp Hair[b]
Permanent Set, (%)	15.7 ± 0.9	12.7 ± 1.1
Supercontraction, (%)	25.7 ± 1.1	19.0 ± 1.5

[a]Bulk hair from ten subjects.
[b]Bulk hair from De Meo Brothers. Values are averages of four determinations along with standard deviations.

In boiling sodium bisulfite, a disulfide bond cleaving agent, the beard hair attained higher levels of permanent set and supercontraction than the scalp hair (Table VII). The results indicate that the facial hair, having a lower level of stabilizing disulfide links, is more susceptible to molecular rearrangements.

CONCLUSIONS

A comparative study of the morphology, chemical composition, mechanical properties, and chemical reactivity revealed significant differences between scalp hair and facial hair.

Morphologically, differences were found between beard and scalp hair in cross-sectional area and shape, number of cuticle layers, cuticular pattern and medullation, in all three ethnic groups investigated. In addition, racial origin leads to minor variations in fiber size, geometry, and pigmentation.

Chemically, the most significant difference between the two fiber types was the lower disulfide bond density in beard hair, as indicated by its lower cystine content. The lower elastic modulus, faster swelling rate, and higher reaction rate of beard hair with a variety of reagents was the result of the less extensive disulfide bonding in this fiber than in scalp hair.

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