Scanning Microscopy

Volume 4 | Number 2 Article 16

6-1-1990

Human Hair Morphology: A Scanning Electron Microscopy Study on a Male Caucasoid and a Computerized Classification of Regional Differences

W. M. Hess
Brigham Young University

R. E. Seegmiller
Brigham Young University

J. S. Gardner
Brigham Young University

J. V. Allen
Brigham Young University

Susan Barendregt
Brigham Young University

Scanning Microscopy, Vol. 4, No. 2, 1990 (Pages 375-386)
Scanning Microscopy International, Chicago (AMF O'Hare), IL 60666 USA

0891-7035/90$3.00+.00

HUMAN HAIR MORPHOLOGY: A SCANNING ELECTRON MICROSCOPY STUDY ON A MALE CAUCASOID AND A COMPUTERIZED CLASSIFICATION OF REGIONAL DIFFERENCES

W. M. Hess, R. E. Seegmiller[1], J. S. Gardner, J. V. Allen, and Susan Barendregt[2]

Department of Botany and Range Science, [1]Department of Zoology, [2]Department of Statistics, Brigham Young University, Provo, Utah 84602

(Received for publication October 16, 1989, and in revised form June 1, 1990)

Abstract

The present study was performed to provide a better understanding of the morphological variations of mammalian hair. Terminal hair samples were obtained from different regions of the body of the same Caucasian male. All hair samples were either cleaned or treated before being examined with scanning electron microscopy. As human scalp hair grew it appeared small like lanugo hair, but the increase in diameter appeared to have been relatively rapid. As hair increased in diameter the appearance of the scales changed. Neck hair was slightly smaller in diameter than scalp hair, and axillary hair was slightly smaller in diameter than neck hair. Nostril hair was larger than scalp or axillary hair. Eyelash hair was much smaller and much shorter than eyebrow hair. Neck hair, forearm hair, and shin hair were smaller than hair from most other regions of the body. Chest hair was similar in size to scalp hair, and pubic and sideburn hair were larger than scalp hair. A morphological feature called "steak-boning" was more characteristically present in whiskers of Caucasoids than Orientals or Blacks. "Steak-boning" occurred most frequently in hair of the mustache, followed by that of the chin, sideburn, cheek and under the chin. Cut surfaces of whiskers were different for electric as compared with straightedge razors. Hair morphology varied relative to the body region. Computer analysis of resin-embedded hair made it possible to classify arm, mustache, cheek, chin, head, shin, and pubic hair, and to quantify cross-sectioned differences.

KEY WORDS: Human hair, computer analysis, hair size, scanning electron microscopy, light microscopy, male caucasoid

*Address for correspondence:
W.M. Hess, Electron Optics Laboratory
129 WIDB, Brigham Young University
Provo, UT 84602 U.S.A.
Phone No. (801) 378-2451

Introduction

Biologists who summarized early hair studies (Braun-Falco, 1958; Parakkal, 1969) and used electron microscopy in early investigations (Orwin et al., 1973; Rogers, 1959) helped pave the way for later studies (Rogers, 1989; Valkovic, 1988). Although several relatively recent light and electron microscopy studies of human hair have been published (Barth, 1986,1987; Choudhry et al., 1983; Lindelöf et al., 1988; Lunde, 1984; Orfanos, 1979; Price and Griffiths, 1985; Riggott and Wyatt, 1983; Seago and Ebling, 1985; Whiting, 1987) there is insufficient information concerning the morphological variation existing for the different body regions of an individual and from individual to individual.

A human hair is composed of an outer cuticle (scales), a cortex of hard keratin constituting 75-97% of the hair shaft and a middle layer (medulla) comprised of soft keratin (Powitt, 1980). The medulla may be discontinuous or absent while the cortex gives the hair fiber its strength. A human hair is stronger than a copper wire of the same diameter and can support a weight of 5-7 oz. Wet hair can soak up to 33% moisture causing up to 14% increase in diameter and resulting in increased tensile strength. Dry hair has a low tensile strength and is more inclined to mat, knot and have split ends (Powitt, 1980).

Hair texture is related to diameter, properties of the cuticle, genetic characteristics, length, direction of growth, and cortical moisture level. Hair diameter varies greatly among individuals and from the different body regions. In forensic studies four important properties of hair are employed: thickness of the shaft, characteristics of the cuticle including scale properties, kinds and amounts of pigment, and morphology of the medulla. However, the appearance of hair can easily be altered by such factors as weathering (Venning et al., 1986), abnormalities of the hair shaft (Whiting, 1987), disease (Lubach, et al., 1982; Orfanos, 1979) and invasion by microorganisms (Okuda et al., 1988; Shelley and Miller, 1984; Shelley et al., 1987; Takatori et al., 1983).

Although hair morphology and length in humans vary from body region to body region,

different classes of hair are recognized (Price and Griffiths, 1985; Rook, 1965). Prenatal hair or lanugo, is fine and soft, unmedullated, normally unpigmented and short (approximately 12 mm in length). Lanugo hair is replaced by vellus hair in postnatal life. The latter is unmedullated and spread over the body surface. It too is soft and short, rarely exceeding 2 cm in length, but is occasionally pigmented. Longer, coarser hair is called terminal hair. It is both medullated and pigmented. Hair in the transition between vellus and terminal is called intermediate.

A categorization of human hair, based on length and function, is often used (Powitt, 1980). Follicle structure does not appear to differ for the different hair types of an individual. Primary hair includes lanugo and vellus hair or the very fine hair present on smooth skin. Since this hair is normally fine, unpigmented, and short, it is difficult to see without magnification aids. Sebaceous glands are present although arrector pili muscles are not.

Secondary hair includes the stiff, relatively short, bristly hair of the eyelashes, eyebrows, ears and nostrils. This type of hair is not associated with arrector pili muscles. Secondary hairs characteristically increase in number and thickness with age and may be curved. The medulla is prominent although secondary hair is normally only 12-25 mm in length. Secondary hairs may be pigmented, are sensitive to touch, and are normally retained even in extreme cases of baldness.

Tertiary or terminal hair is the predominant hair of the scalp, beard, legs, arms and body in both sexes. Individual hairs normally grow in groups of two to five, and, except in albinos, are pigmented. Danforth (1925) reported that approximately 90% of the hair on the chest, shoulders, legs and arms of men is terminal hair. Only 35% of this hair in women is terminal.

Riggott and Wyatt (1983) measured hair shaft diameters and counted scales for ten different body sites which enabeled them to classify hair into three distinct types: (a) scalp, (b) eyebrow and eyelash, and (c) hair from other areas of the body. Androgen-dependent sites consistently had thicker hair shafts. Subjects with skin diseases frequently had hair diameter scale patterns that did not fit the norm, as has been demonstrated by others (Escobar et al., 1983; Orfanos, 1979; Ortonne et al., 1985; Prens et al., 1984; Sala et al., 1983; Zitelli, 1986). More recently Valkovic (1988) listed six morphological types of hair: (a) head, (b) eyebrow and eyelash, (c) beard and mustache, (d) body hair, (e) pubic hair, and (f) axillary hair.

In addition to improving or detracting from ones appearance, depending on personal perception, hair serves several useful functions. Eyebrows divert perspiration from the eyes, eyelashes trigger eyelids to close to prevent injury from foreign objects, and small hairs in the ears and nostrils filter foreign objects. Pubic and axillary hair reduce friction during body movement, and scalp hair insulates the head during summer and winter.

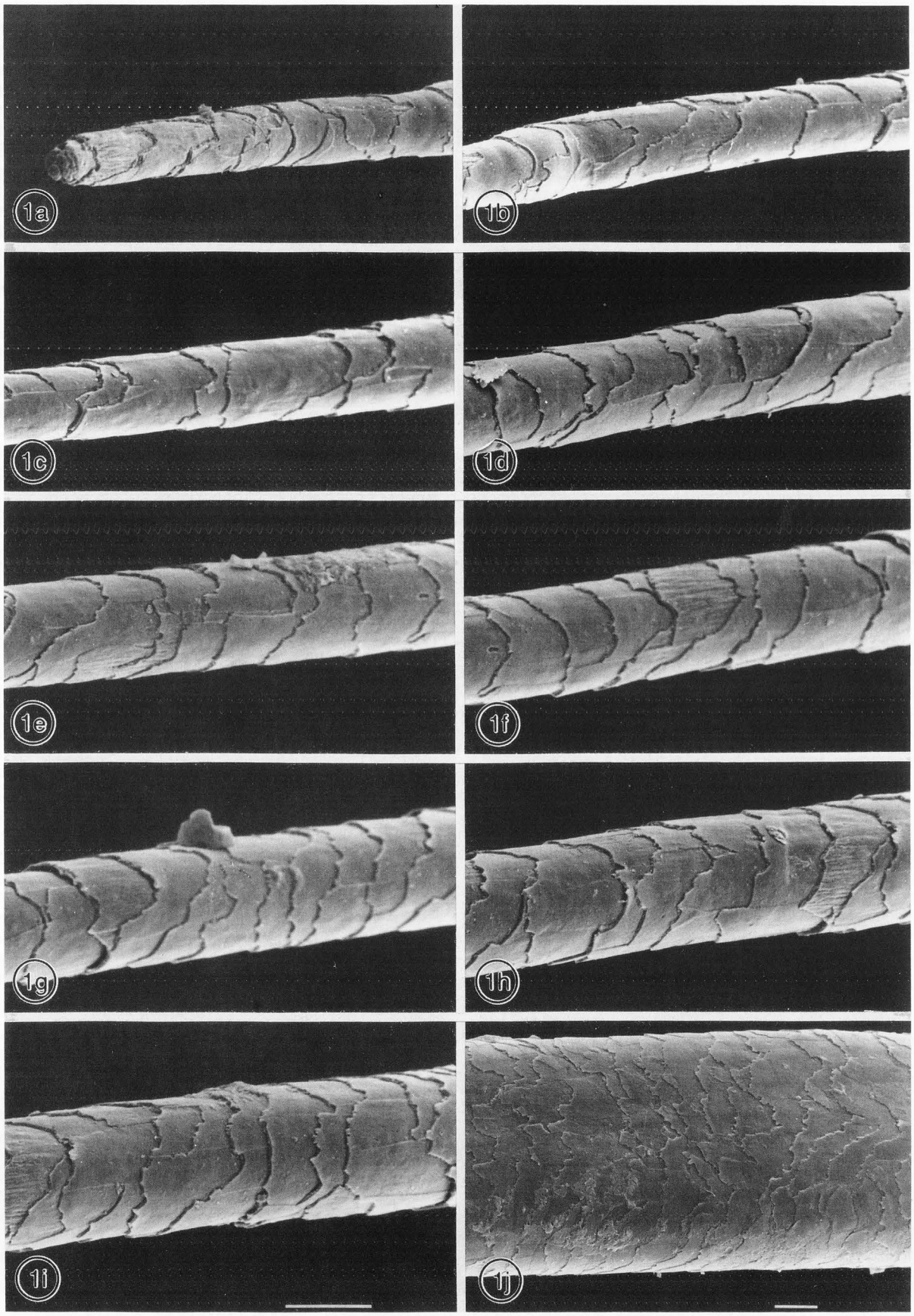
Hair shape and texture are determined by the size and shape of hair follicles. In a cross-section, a straight hair is relatively rounded whereas a curly hair is oval. Scalp hair diameter differs significantly from person to person even among individuals within the same family. It has been confirmed with three-dimensional reconstruction methods that follicle morphology determines hair morphology (Lindelöf et al., 1988). The follicle in Blacks has a helical form compared with that of Orientals which is completely straight. Follicle structure in Caucasoids varies between these extremes, although a straight Caucasoid follicle can produce a hair with an oval shaft. In his review, Barth (1987) pointed out that racial differences in hair morphology have been observed for average diameter, degree of medullation, shaft cuticular scale count, average curvature, kinking, crimp, maximum/minimum curvature, and natural/extended length. In a survey of 100,000 American soldiers, 90% had brown hair, 5% flaxen, 4% black, and 1% red (Danforth, 1925). Children's hair is usually lighter than adults' (Barth, 1987). Hair of Mongoloid and Negroid races has predominantly brown-black tones. Although uncommon among Japanese, red hair occurs in most human populations. The frequency of red hair was 0.13% in Japanese, 0.2% in African Blacks, 0.2% in Ashkenazi Jews, 2.03% in English school children, and 5.3% in Scottish children (Pinkus, 1927).

In their published review on human body hair, Price and Griffiths (1985) concluded that the number of follicles is approximately the same in both males and females (5 million). There are approximately 140,000 terminal scalp hairs in light-haired individuals, 102,000 in dark-haired individuals, and only 88,000 in red-haired individuals. An average loss of 100 hairs per day from the scalp is common, and the density of follicles in the scalp decreases with age. Giacometti (1965) observed that individuals 20-30 years of age had an average of 615 hair follicles/cm^2, whereas individuals 80-90 years of age had 435/cm^2. Bald adults 45-60 years of age had fewer follicles averaging only 305 follicles/cm^2. A range of follicle density from 45-60/cm^2 on the lower limbs to 700/cm^2 on the face was also reported (Valkovic, 1988).

Patterns of hair growth were reviewed by Price and Griffiths (1985). The various stages of the hair cycle are referred to as anagen (the active growth phase), catagen (the regression phase), and telogen (the resting period). In humans, the length of the hair cycle varies for the different body regions. Scalp hair has a longer cycle than hair from other body regions. Pinkus (1947) suggested that body hairs fall out after 107-195 days with

---

Figs. 1a-1j. Figures 1a-h are successive photos of the tip of a terminal human Caucasian forehead hair. Figure 1j is near the base of the hair shaft. Figs. 1a-1j. Bar = 10 μm.


1a
1b
1c
1d
1e
1f
1g
1h
1i
1j

hairless intervals for a given follicle ranging from 27 to 92 days.

Rates of hair growth in non-diseased women have been estimated to be 0.37 mm/day for scalp, 0.80 mm for the forearm and 0.30 mm/day for thigh hair (Munro, 1966; Price and Griffiths, 1985). The mean rate of growth for the forearm of non-diseased males was 0.28 mm/day (Comaish, 1969; Price and Griffiths, 1985). Thus, if the 6,000 to 25,000 hairs in a Caucasoid beard grew at a rate of 0.4 to 0.5 mm/day (approximately 1/2 inch/month), it would take about two months to grow one inch (2.54 cm). If beard hair is replaced at a similar rate as for other hair, maximum beard length would be determined by the rate of hair replacement.

Seago and Ebling (1985) studied the hair cycle on human thighs and upper arms for both males and females. They observed that hair follicle density was not different between males and females. Yet male thigh hair was three times longer than that of females due to a longer duration of anagen and a faster growth rate. Upper arm hair was also longer in males and the duration of anagen was greater. These studies demonstrate a few of the differences in hair morphology and growth rate between the sexes.

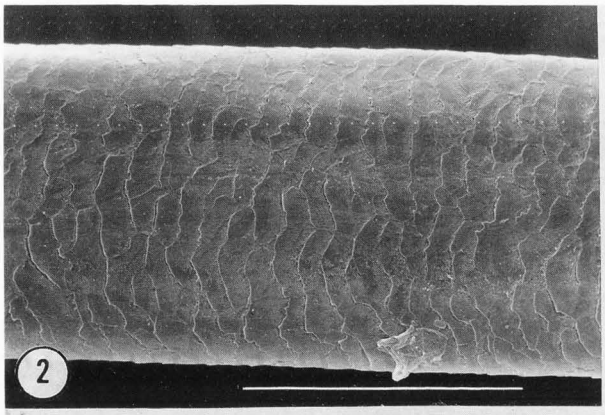
Although most studies have been conducted on normal hair, a few studies have been conducted on hair from individuals with unusual or pathological conditions. The scanning electron microscope has been a superb tool for providing a better understanding of normal and altered hair morphology (Baraitser and Patton, 1986; Forslind and Kaaman, 1984; Forslind et al., 1985; Goldin et al., 1984; Pichardo, 1983; Ravella, et al., 1987; Zegpi and Roa, 1987). Not only has it permitted a better description of the disease or condition, but it has provided clues as to the cause of the condition (Hebert et al., 1987). It has also allowed us to evaluate at the ultrastructural level, morphological differences in hair from one area of the body to another, and to characterize differences from individual to individual and between racial types. Such information is useful in medicine, anthropology, and forensics. However, more complete, and often more useful data can be obtained by comparing data obtained with light and electron microscopy. The purpose of the present study was to use light and scanning electron microscopy to provide a better description of the morphological differences of hair from different body regions of a single Caucasian male.

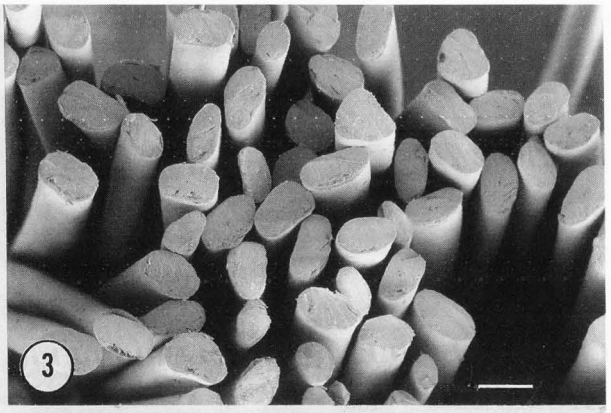
Materials and Methods

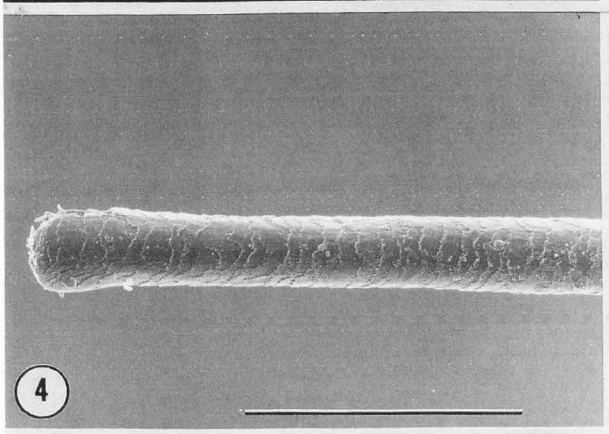
Untreated hairs from different regions of a 50 year-old Caucasian male were cleaned according to the procedure of Hess et al. (1985), which consisted of placing hair samples in small dishes of distilled water containing a drop of detergent (Shell Teepol) and sonicating for 5 min. Hairs were then washed in distilled water, sonicated for 5 min. in desiccated acetone, and either air dried, blotted on Kimwipes, or blown dry with freon in a duster before being mounted on SEM stubs. A single scalp hair was also studied as it emerged from the follicle, and diameter measurements for hair size comparison studies of clean hair were made with a Mitutoyo toolmaker's microscope series 176. Computerized image analysis of resin-embedded hair was according to the procedures of Hess and Seegmiller (1988) and a stepwise discriminant analysis was performed on the raw data, area of a cross-section of hair, perimeter of a cross-section, and perimeter to area ratio of a cross-section. Once the discriminant analysis was completed, each observation was classified according to the derived discriminant function. This initial classification was used as a guide in grouping some of the categories (locations of hair on the body) together in order to come up with a more concise list of categories, and thereby a more accurate classification of observations.

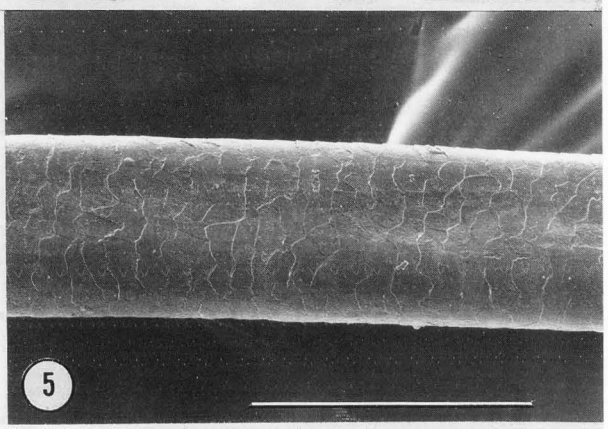
Whiskers were cleaned according to the procedures of Hess and Allen (1985), which consisted of having individuals shave and then wait 15-18 hr before shaving again to obtain whiskers of the proper length. For straightedge cuts shaving cream was used. For electric razor cuts a Norelco electric razor was used. Whiskers and shaving cream were washed into small wide-mouth containers. The containers were swirled to concentrate the whiskers in the center of the bottom of the jar. Whiskers were then transferred with disposable pipettes to clinical centrifuge tubes. Detergent was added to reduce surface tension and distilled water was added before the samples were shaken. The supernatant was discarded after the whiskers settled to the bottom of the tube. The whiskers were washed several times in acetone before being transferred to a small dish containing desiccated acetone in which they were sonicated 4-5 min. The dishes were swirled again to concentrate the whiskers in the center of the dish. The debris was removed with a disposable pipette and sharp forceps. The whiskers were transferred with a clean disposable pipette to a filter paper cone where they were washed to the bottom of the cone with acetone. After they had dried, inverted SEM stubs coated with double-coated tape were pressed onto them and excess whiskers were blown off the stubs with a freon duster.

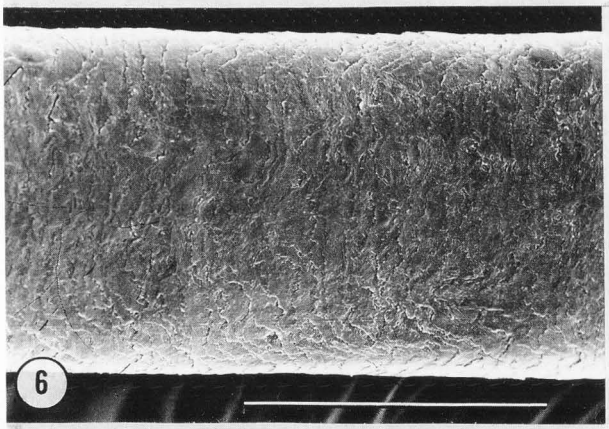
Figs. 2-9. Terminal human hair from a Caucasian male (same individual as in Fig. 1). Fig. 2. Terminal scalp hair showing the normal scale pattern. Fig. 3. Cross-section of scalp hair showing variation of oval to round hair shafts. Fig. 4. Tip of a neck hair. Fig. 5. Surface of a neck hair. Fig. 6. Axillary hair. Note that the scales appear to be worn. Fig. 7. Nostril hair showing longitudinal undulations. Fig. 8. Forearm terminal hair showing longitudinal undulations. Fig. 9. Forearm vellus hair showing the characteristic scale pattern. Figs. 2-8. Bar = 100 μm. Fig. 9. Bar = 10 μm.

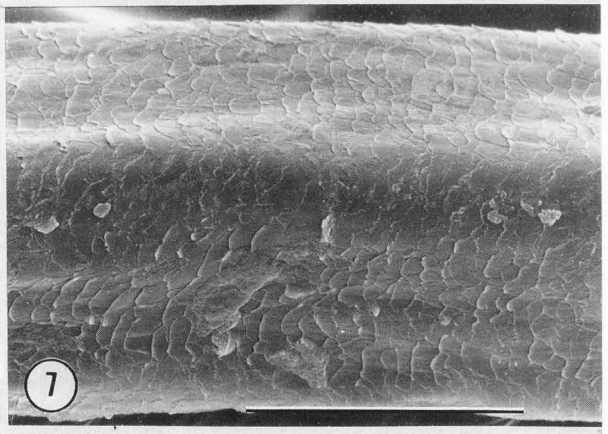

2

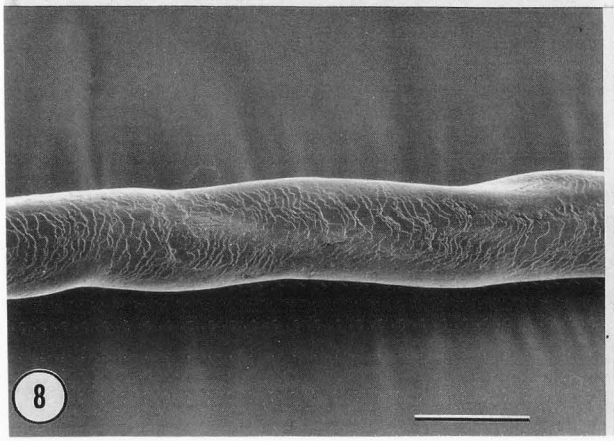

3

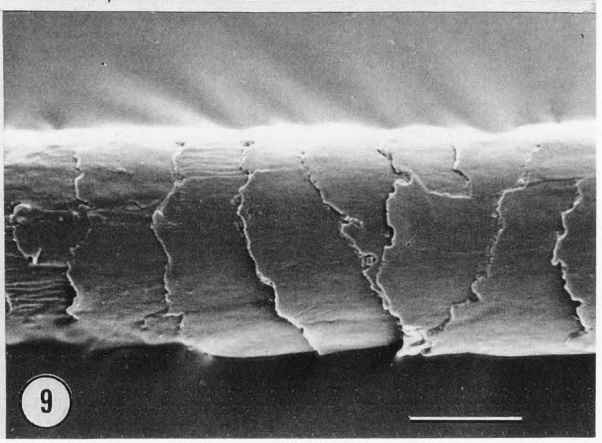

4


5


6


7


8


9

To prepare cross-sections for SEM, bundles of hair were placed between pieces of balsa wood or were placed in small tubes to keep the bundles tight for cutting with sharp razor blades or obsidian blades fractured from blocks of obsidian. Specimens were gold coated before being examined with an AMRay 1000A or JEOL 840A SEM.

Results and Discussion

Morphological differences of terminal body hair

The average diameters of terminal hair from 19 areas of a fifty-year old Caucasian male are shown in Table 1. Hair from all areas studied appeared irregular in diameter. Because oval hair shafts had a tendency to curve and lie on their sides, the diameters appeared slightly less than had they been oriented such that the measurements could have been taken at the widest point of the oval. Therefore, these data provide indications of trends, but do not provide the precision obtained from cross-section studies utilizing computer analysis to obtain area and perimeter values (Hess and Seegmiller, 1988). Nevertheless, the relative differences among hair samples provided useful information. Forearm, axillary, wrist and shin hair had the smallest diameter. All appeared slightly smaller in diameter than scalp hair. Pubic hair and hair from other regions of the face and head were larger in diameter than scalp hair. Some variability in average diameter of hair from the mustache and beard was evident. Hair with the largest diameter included beard, mustache and eyebrow. Scanning electron micrographs shown in Figs. 1-17 are of human terminal hair samples taken from the same Caucasian male (Table 1). Although there was some variability in hair morphology for each of the areas shown, representative samples are shown in each instance.

When human scalp hair begins to form, it is small at the tip (Fig. 1a-1i) like lanugo hair. The increase in diameter is relatively rapid and the hair has a more characteristic terminal scalp hair appearance by the time it is 2.5-3 cm in length (Fig. 1j). With newly grown, untreated hair the scales were tightly adpressed to the hair shaft, although on delicate hair tips occasional flaring was seen (Fig. 1g). In this instance, the younger portions of the shaft had scales with serrated edges (Fig. 1j). The mature hair shafts which had reached maximum diameter had scales with a less serrated edge (Fig. 2).

Human Caucasian terminal scalp hair from the individual studied was characteristically oval to round when viewed in cross-section, with some variation in shape and size (Fig. 3). Mature terminal hairs from the scalp (Fig. 2), neck (Figs. 4-5), axillary (Fig. 6), and nostril (Fig. 7) are shown at the same magnification. Neck hair was smaller in diameter than scalp hair, and axillary hair was similar in size to scalp hair, but the scales on axillary hair were often difficult to distinguish presumably because of the constant contact with clothing and the rubbing action on this part of the body. Nostril hair was generally larger than scalp or axillary hair and often had longitudinal depressions (Fig. 7).

A relatively easy body region to observe both terminal and vellus hair was on the forearm (Figs. 8-9). Terminal hair on the forearm had a delicate appearance with the unaided eye and often an undulating pattern was observed with magnification (Fig. 8). Vellus hair was so small it was necessary to use higher SEM magnifications to visualize the scale characteristics (Fig. 9).

Although length and diameter of facial hair varies among individuals, we observed that for the individual studied, eyelash hair (Fig. 10) was thinner and shorter than eyebrow hair (Fig. 11). Both types of hair were normally larger in diameter than terminal scalp hair. Lunde (1984) studied the distribution and density of terminal hair in 19 different body regions in normal women of fertile age and reported age-dependent variations in hair growth patterns. This investigator did not observe differences in hair growth patterns between blonds and brunettes but reported evidence for racial and ethnic differences. Nevertheless we observed that shin hair (Fig. 12) was relatively short and smaller in diameter than scalp hair (Table 1). Chest hair (Fig. 13) was similar in diameter to scalp hair, and wrist hair (Figs. 14-15) was similar with respect to size and scale patterns to shin hair. Sideburn hair was similar in diameter amd physical appearance to pubic hair. Pubic hair (Figs. 16-17) was more oval than scalp hair (Figs. 2-3) and had an undulating appearance when viewed at higher magnifications (Fig. 17).

Variations in whisker morphology and shaving effects

Although we have studied only a few whisker samples of Oriental and Black individuals, we have examined whisker samples from more than three dozen Caucasoids (Hess and Allen, 1985; Hess and Seegmiller, 1988). Caucasoids had irregular shaped whiskers (Fig. 18) which we have termed "steak-boning" (Fig. 19). This characteristic of human terminal hair was only observed for facial hair. Some individuals had more "steak-boning" than others and the amount of "steak-boning" was more prevalent for mustache than for other facial hair, followed by the chin. It was less common on the cheeks and under the chin. It was much less prevalent with Oriental and Negroid whisker samples, sometimes barely discernable, or not seen at all. The characteristic appears to be inherited

---

Figs. 10-17. Terminal human hair from a Caucasian male (same individual as in Figs. 1-9). Fig. 10. Eyelash hair. Fig. 11. Eyebrow hair. Fig. 12. Shin hair. Fig. 13. Chest hair. Fig. 14. Wrist hair. Fig. 15. Tip of wrist hair. Fig. 16. Tuft of pubic hair. Fig. 17. Surface of pubic hair. Figs. 10-16 Bar = 100 μm. Fig. 17. Bar = 10 μm.

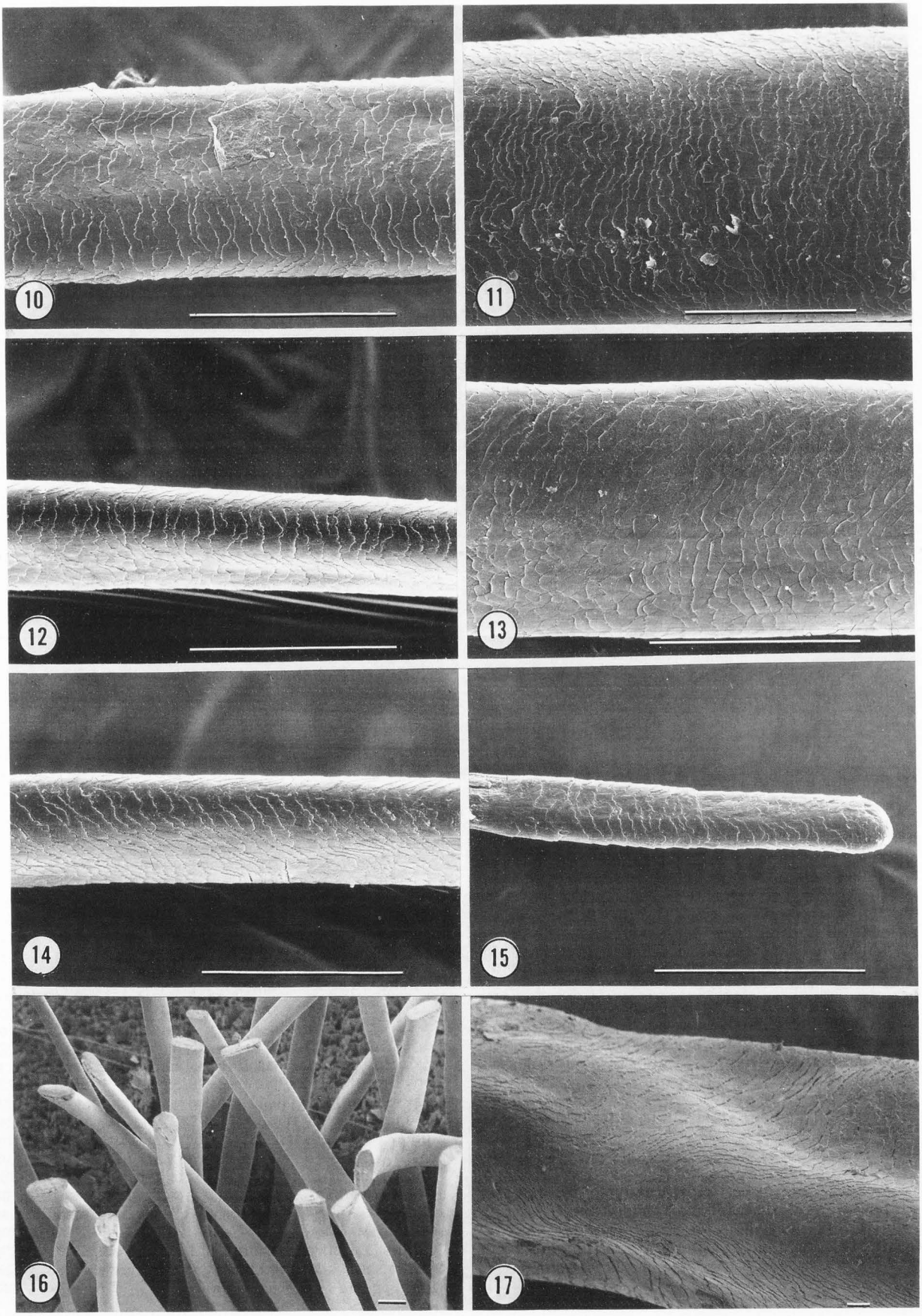
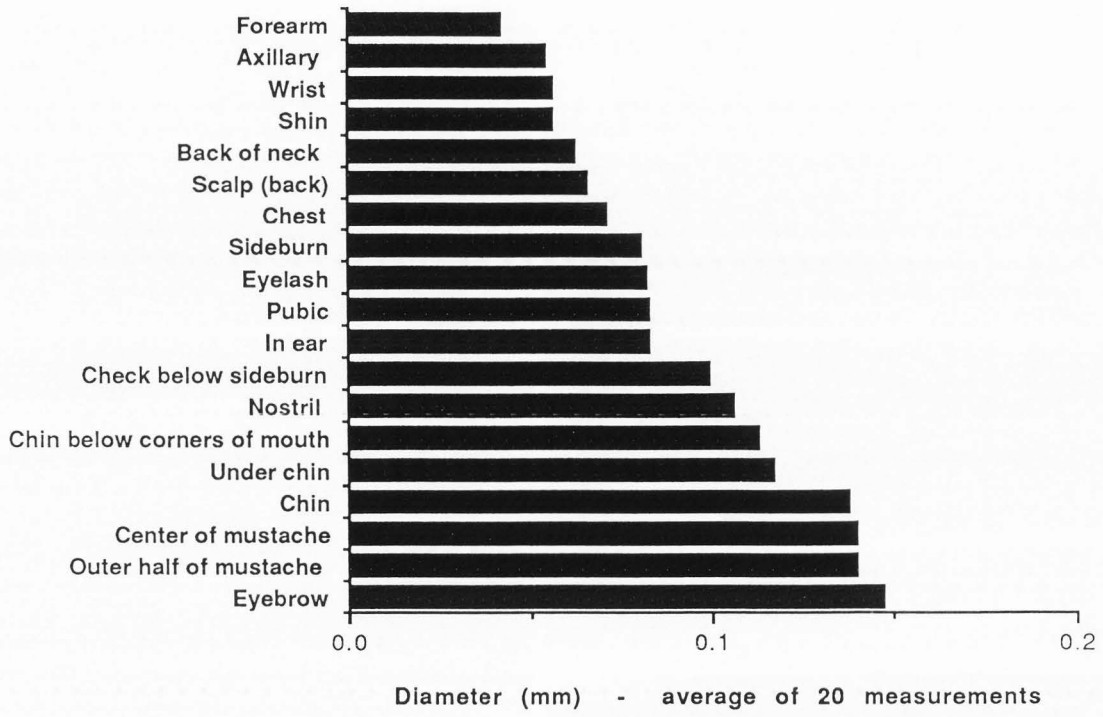

10
11
12
13
14
15
16
17

Table 1. Diameter of hair in relation to location on the body



independently from beard density as some Caucasoid individuals who did not have enough whiskers to grow a beard or mustache also had prominent "steak-boning" (unpublished observations).

Whiskers cut with an electric razor were broken into pieces such that small fragments obliterated much of the detail of the larger pieces (Fig. 20). However, The larger pieces were more easily visualized (Fig. 21) in samples that were cleaned (Hess and Allen, 1985). If an individual shaved successively with an electric razor both ends of the cut fragments had rough cuts (Fig. 21). This may not be true for all brands of electric razors. If a whisker sample was cut first with a straightedge razor followed by an electric razor, most of the cut ends were rough and only an occasional end had a smooth cut (Fig. 22). The reason is that when whiskers were shaved many passes of the razor were made, a common procedure when shaving. This resulted in multiple cuts of the same type. Whereas, there was a finite number of exposed cut hair shaft ends from the previous shave. The cut ends were identical in appearance if successive shaves were with the same razor or the same type of razor. Figure 23 shows a whisker sample where the whiskers were cut first with an electric razor, followed by a straightedge razor. In this instance most of the cut surfaces were smooth straightedge cuts.

Although morphology of whiskers from different areas of the face was studied for only a few individuals, in all instances the "steak-boning" characteristic was much less prominent under the chin (Fig. 24) and on the cheeks (Fig. 25). It was more difficult to obtain good SEM samples of whiskers from the sideburns and cheeks because of the tendency of the follicles to grow at an angle

Figs. 18-25. Whiskers from a Caucasian male (same individual as in Figs. 1-17). Fig. 18. Whiskers from the center of the mustache. Fig. 19. Cross-section of individual whisker from the center of the mustache showing the characteristic, irregular shape, or "steak-boning". Fig. 20. A whisker sample cut with a Norelco electric razor. Note pieces of skin and broken pieces of whisker. Fig. 21. A "cleaned" sample of whiskers cut with a Norelco electric razor. Both ends of the whiskers were cut with an electric razor. Fig. 22. Whisker sample where the whiskers were cut first with a straightedge, followed by an electric razor. Fig. 23. Whisker sample where the whiskers were cut first with an electric razor, followed by a straightedge. Fig. 24. Whiskers from under the chin on the neck where the "steak-boning" is much less evident. Fig. 25. Whiskers from the cheek below the sideburns. Note that in this region, where the hair has a tendency to grow at an angle, the whiskers are sometimes cut into strips. Also note three hair shafts which have been pulled out during shaving. The ends of the hair shafts which were in the follicle are expanded and appear fuzzy. Figs. 18,19,21-23. Bar = 100 µm. Figs. 20,24-25. Bar= 1 mm.

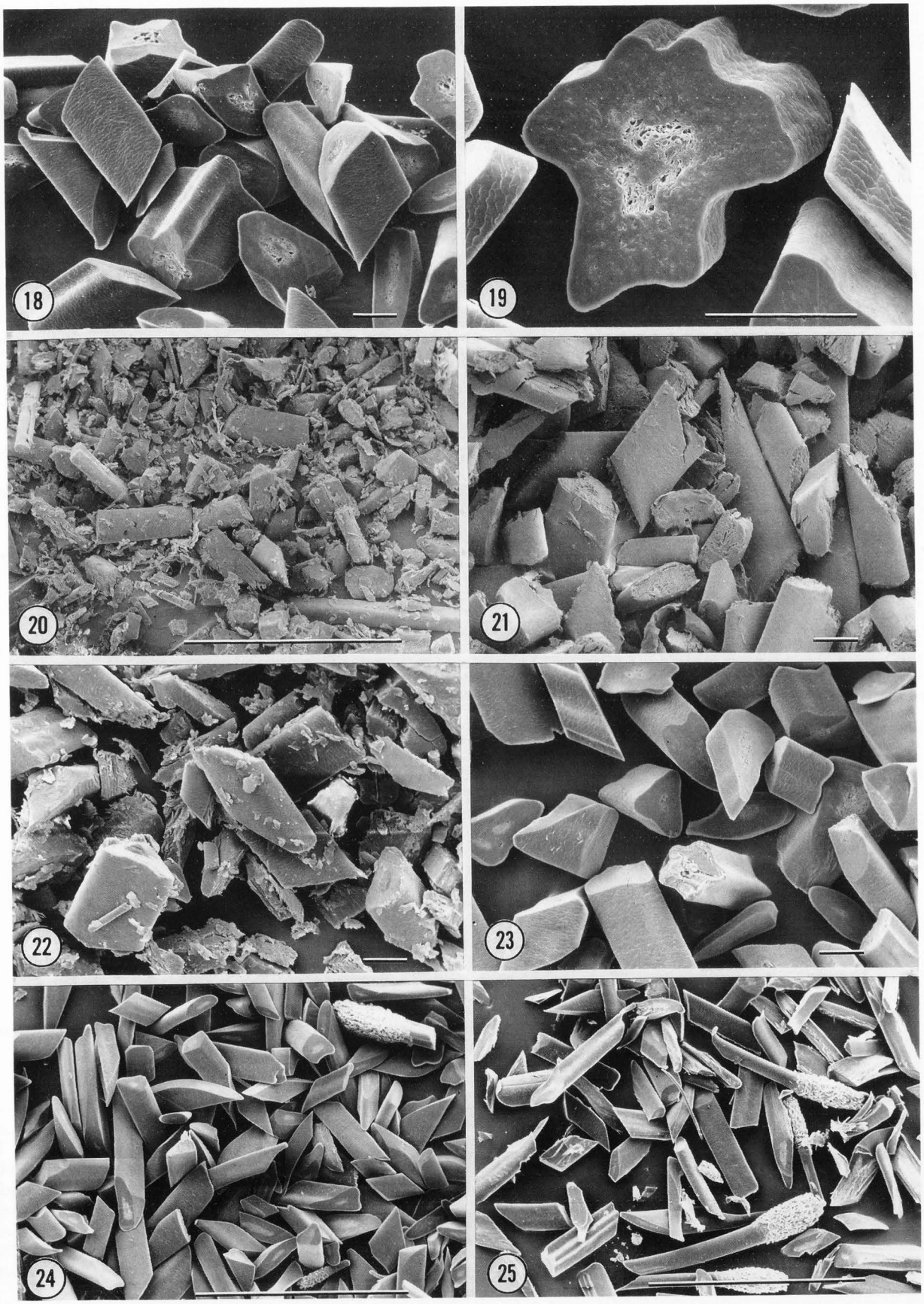

18
19
20
21
22
23
24
25

Table 2. CLASSIFICATION - %

	ARM	MUSTACHE	CHEEK	CHIN	HEAD	SHIN	PUBIC
ARM	68	0	0	0	6	26	0
MUSTACHE	0	62	1	37	0	0	0
CHEEK	0	0	62	22	3	1	12
CHIN	0	6	26	63	0	0	5
HEAD	0	0	0	0	72	20	8
SHIN	8	0	0	0	10	82	0
PUBIC	0	0	48	2	12	0	38

rather than perpendicular to the skin surface. Thus when cut with a straightedge, the hair shafts were cut at an angle (Fig. 25) less than perpendicular. Most whisker samples also contained short hair shafts which were pulled out of the follicles (Fig. 25).

Computerized image analysis of resin-embedded hair

Although it is possible to obtain general information about hair diameter by measuring individual hairs (Table 1), a more accurate comparison can be made by using computerized methods to study resin-embedded whiskers and other hair (Hess and Seegmiller, 1988). Figures 26-36 show cross-sectional diagrams of hair from different regions of the body of the individual studied. Each observation was classified according to the derived discriminant function. This resulted in regrouping of categories which could not be statistically separated from each other. All mustache hair was grouped into the same category. Cheek and sideburn hair was grouped together. Hair at the side of the chin under the mouth, on the chin, and under the chin was also grouped together. This resulted in seven categories of hair which were classified according to the derived discriminant function. Percent classification was determined for each category (Table 2).

This provided a means to determine where an individual hair could be classified. Arm hair was only classified as arm hair or shin hair. Mustache hair was classified only as mustache or chin hair, and to a lesser extent, cheek hair. Some cheek hair was variable enough in size to be classified as head or shin hair. Head hair was classified only as head hair, shin hair or pubic hair, but not as facial hair. Shin hair was too small to be classified as facial hair. Pubic was classified as cheek or sideburn hair more often than it was classified as pubic hair. Although these studies were limited to a single Caucasian individual, they provide a means to better understand cross-sectional characteristics of hair. Similar studies are presently being conducted with other Caucasian individuals to determine how much variation there is in hair characteristics from individual to individual.

References

Baraitser M, Patton MA. (1986). A noonan-like short stature syndrome with sparse hair. J. Med. Genet. 23, 161-164.

Barth JH. (1986). Measurement of hair growth. Clin. Exp. Dermatol. 11, 127-138.

Barth JH. (1987). Normal hair growth in children. Pediatric Dermatol. 4, 173-184.

Braun-Falco O. (1958). The histochemistry of the hair follicle, In Mantagna-Ellis: The biology of hair growth. Academic Press. New York, London, 65-90.

Choudhry MY, Kingston CR, Kobilinsky L, DeForest PR. (1983). Individual characteristics of chemically modified human hairs revealed by scanning electron microscopy. J. Forensic Sci. 28, 293-306.

Comaish S. (1969). Autoradiographic studies of hair growth in various dermatoses. Investigation of a possible circadian rhythm in human hair growth. Brit. J. Dermatol. 81, 238-288.

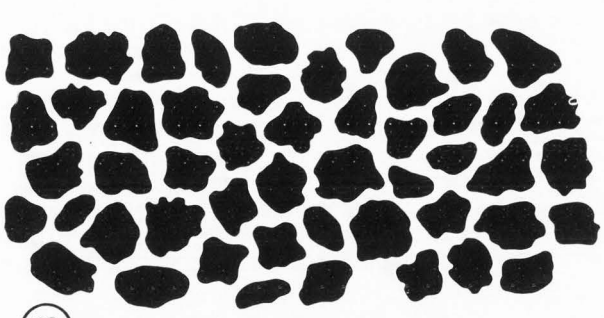
Danforth, CH. (1925). Hair. American Medical Association Press, Chicago.

Escobar V, Goldblatt LI, Bixler D, Weaver D. (1983). Clouston syndrome: an ultrastructural study. Clin. Genet. 24, 140-146.

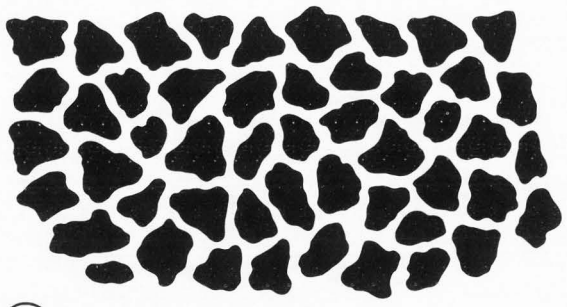
Forslind B, Kaaman T. (1984). Brittle hair in osteogenesis imperfecta: Transmission and scanning electron microscopy and mycologic assay. Acta Derm. Venereol. (Stockh) 64, 418-455.

Forslind B, Thomsen K, Andersson B. (1985). Spun glass hair: Two cases investigated with SEM and TEM. Acta Derm. Venereol. (Stockh) 65, 348-352.

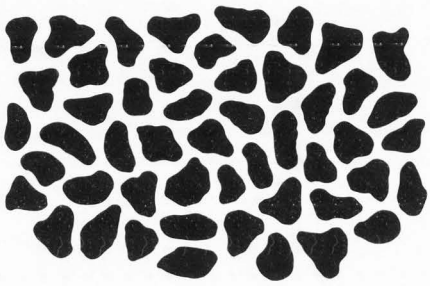
Figs. 26-36. Cross-sectional diagrams of hair from a Caucasian male (same individual as in Figs. 1-25). Fig. 26. Center of mustache. Fig. 27. Side of mustache. Fig. 28. Center of chin. Fig. 29. Side of chin, under mouth. Fig. 30. Cheek between sideburn and chin. Fig. 31. Under chin. Fig. 32. Sideburn. Fig. 33. Pubic. Fig. 34. Back of head. Fig. 35. Shin. Fig. 36. Forearm on the outside just below the elbow. Bar = 100 μm.



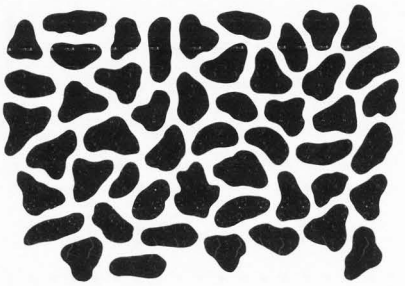
26



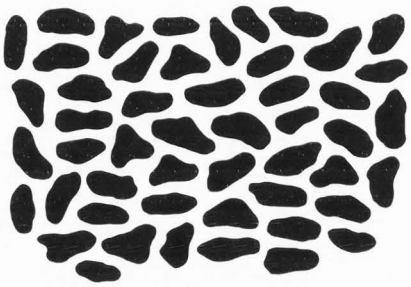
27



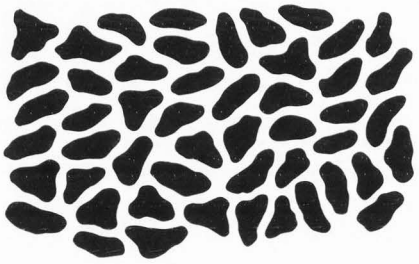
28



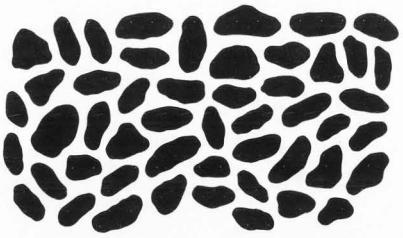
29



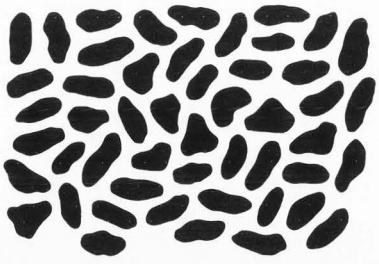
30



31

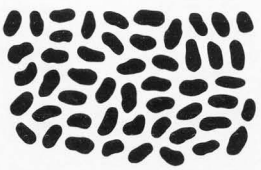


32

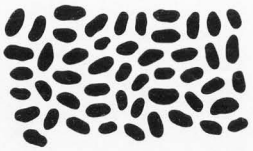


33

34



35



36

Giacometti L. (1965). The anatomy of the human scalp. In: Advances in biology of the skin. Vol. VI, Ageing. Ed. by W. Montagna. Pergamon Press, Oxford. p. 97-120.

Goldin HM, Bronson DM, Fretzin DF. (1984). Woolly-hair nevus: A case report and study by scanning electron microscopy. Pediatric Dermatol. 2, 41-44.

Hebert AA, Charrow J, Esterly NB, Fretzin DF. (1987). Uncombable hair (pili trianguli et canaliculi): Evidence for dominant inheritance with complete penetrance based on scanning electron microscopy. Amer. J. Med. Genet. 28, 185-193.

Hess WM, Allen JV. (1985). Preparation of human whisker samples for scanning electron microscopy. J. Elect. Microsc. Tech. 2, 393-394.

Hess WM, Flinders JT, Pritchett CL, Allen JV. (1985). Characterization of hair morphology in families tayassuidae and suidae with scanning electron microscopy. J. Mamm. 66, 75-84.

Hess WM, Seegmiller RE. (1988). Computerized image analysis of resin-embedded hair. Trans. Am. Microsc. Soc. 107, 421-425.

Lindelöf B, Forslind B, Hedblad M, Kaveus U. (1988). Human hair form: Morphology revealed by light and scanning electron microscopy and computer aided three-dimensional reconstruction. Arch. Dermatol. 124, 1359-1363.

Lubach D, Glowienka F, Castellucci M. (1982). Monilethrix: Comparative scanning electron microscopic study of the hair in one family. Dermatologica 164, 1-9.

Lunde O. (1984). A study of body hair density and distribution in normal women. Amer. J. Physical Anthropol. 64, 179-184.

Munro D. (1966). Hair growth measurement using intradermal sulphur 35 cystine. Arch. Dermatol. 93, 119-122.

Okuda C, Ito M, Sato Y. (1988). Fungus invasion into human hair tissue in black dot ringworm: Light and electron microscopy study. J. Invest. Dermatol. 90, 729-733.

Orfanos CE. (1979). Haar und haarkrankheiten. Gustav Fischer Verlag, Stuttgart. 1103 pp.

Ortonne JP, Juhlin L, El Baze P, Pautrat G. (1985). Familial rolled and spiral hairs with palmoplantar keratoderma. Acta. Derm. Venereol. (Stockh) 65, 250-254.

Orwin DFG, Thomson RW, Flower NE. (1973). Plasma membrane differentiations of keratinizing cells of the wool follicle. J. Ultrastruct. Res. 45, I. Gap junctions 1-14; II. Desmosomes 15-29; III. Tight junctions 30-40.

Parakkal PF. (1969). The fine structure of anagen hair follicle of the mouse, In Montagna-Dobson: Hair growth (Advances in biology of skin, Vol. 9), Pergamon press. Oxford, 441-469.

Pichardo AR. (1983). Woolly hair: A proposito de cinco observaciones. Med. Cut. I.L.A. 11, 393-398.

Pinkus F. (1927). Die normale anatomie der haut. In: Jadassohn J. ed. Handbuch der Haut und Geschlechtshrankheiten. Vol. 1. Anatomie der Haut. Springer Verlag, Berlin.

Pinkus F. (1947). The story of a hair root. J. Invest. Dermatol. 9, 91-93.

Powitt AH. (1980). Hair structure and chemistry simplified. Milady Pub. Corp. N.Y., 303 pp.

Prens EP, Peereboom-Wynia JDR, De Bruyn WC, Van Joost Th, Stolz E. (1984). Clinical and scanning electron microscopic findings in a solitary case of trichorhinophalangeal syndrome type I. Acta. Derm. Venereol. (Stockh) 64, 249-253.

Price ML, Griffiths WAD. (1985). Normal bodyhair - a review. Clin. Exp. Dermatol. 10, 87-97.

Ravella A, Pujol RM, Noguera X, de Moragas JM. (1987). Localized pili canaliculi and trianguli. J. Amer. Acad. Dermatol. 17, 377-380.

Riggott JM, Wyatt EH. (1983). Mensuration of scanning micrographs. A possible means of hair identification. J. Forensic Sci. Soc. 23, 155-160.

Rogers GE. (1959). Electron microscopy of wool. J. Ultrastruct. Res. 2, 309-330.

Rogers GE, Reis, PJ, Ward KA, Marshall RC. Eds. (1989). The biology of wool and hair. Chapman and Hall. New York, London, 506 pp.

Rook A. (1965). Endocrine influences on hair growth. Brit. Med. J. I, 609-614.

Sala F, Crosti C, Menni S, Piccinno R, Povia T. (1983). Alterazioni ultrastrutturali del capello indotte da trattamenti cosmetici. Giorn. It. Derm. Vener. 118, 293-295.

Seago SV, Ebling FJG (1985). The hair cycle on the human thigh and upper arm. Brit. J. Dermatol. 113, 9-16.

Shelley WB, Miller MA. (1984). Electronmicroscopy, histochemistry, and microbiology of bacterial adhesion in trichomycosis axillaris. J. Am. Acad. Dermatol. 10, 1005-1014.

Shelley WB, Shelley ED, Burmeister V. (1987). The infected hairs of tinea capitis due to Microsporum canis: Demonstration of uniqueness of the hair cuticle by scanning electron microscopy. J. Am. Acad. Dermatol. 16, 354-361.

Takatori K, Udagawa S, Kurata H, Hasegawa A. (1983). Microscopic observation of human hairs infected with Microsporum ferrugineum. Mycopathologia 81, 129-133.

Valkovic V. (1988). Human hair. Volume I: Fundamentals and methods for measurement of elemental composition. CRC Press, Inc. Boca Raton, Florida. 164 pp.

Venning VA, Dawber RPR, Ferguson DJP, Kanan MW. (1986). Weathering of hair in trichothiodystrophy. Brit. J. Dermatol. 114, 591-595.

Whiting DA. (1987). Structural abnormalities of the hair shaft. J. Am. Acad. Dermatol. 16, 1-25.

Zegpi M, Roa I. (1987). The uncombable hair syndrome. Arch. Pathol. Lab. Med. 111, 754-755.

Zitelli JA. (1986). Pseudomonilethrix: An artifact. Arch. Dermatol. 122, 688-690.

Editor's Note: All of the reviewer's concerns were appropriately addressed by text changes, hence there is no Discussion with Reviewers.