ATLAS OF HUMAN HAIR

Microscopic Characteristics

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Preface

Two problems have confronted researchers and examiners in the forensic examination, comparison, and identification of human hair. First, the ability to describe the microscopic characteristics of hair in a uniform manner among workers in different geographical areas has been frustrated owing to the lack of an atlas that all workers could reference when describing a particular characteristic or one of its variates. Second, the ability of the researcher to develop frequency data for the variates of each characteristic has been hindered owing to the lack of a uniform reference for identifying the specific variate of a microscopic characteristic seen in a study hair. This atlas will remedy those two problems by providing photographic archetypes for human hair microscopic variates that will both provide a vehicle for uniformity in the descriptors for these variates and the partitioning of the microscopic characteristics into variate classes for determination of frequency data for each of the variates in a study population.

The hair atlas also introduces a systematic scoring system that permits the researcher or examiner to easily and rapidly score the variates seen in a study hair. This scoring system will facilitate the development of frequency data for each of the microscopic characteristic variates and for the hair type represented by the specific combination of the characteristic variates found in a study hair.

Although the primary aim of the atlas is to contribute archetypes for the microscopic characteristics of human hair, certain of the macroscopic characteristics are included because those characteristics and their variates are integral to the concept of the hair type. A novel template is provided so that measurement of the hair shaft curvature can be accomplished quickly and scored rapidly.

Chapter 1 introduces the concepts of forensic hair examination necessary for proper use of the atlas. A discussion of the terminology used in the atlas follows, and a brief discussion of the concepts underlying the individualization of physical evidence is provided. The numerical scoring system for describing the microscopic variates is explained so that the user will know how the scoring system operates when examining a study hair. A brief

discussion of the materials and methods used in producing the atlas is provided at the end of the chapter.

Chapter 2 introduces those macroscopic characteristics necessary for identifying the hair type of a study hair and furnishes the template for hair curvature measurement. Those macroscopic characteristics that contribute to the concept of the hair type are the hair form (type of curl), degree of hair curl, and shaft length. These macroscopic characteristics and certain of the microscopic characteristics combine to determine the hair type, as discussed in Chapter 6.

Chapter 3 provides a discussion of each microscopic characteristic and its variates. The microscopic characteristic variates are presented photographically in Chapter 5.

Chapter 4 considers cross-sections of the hair with regard to a number of microscopic characteristics. Photographic archetypes for the variates of the cross-section characteristics are presented in Chapter 5.

Chapter 5 demonstrates the microscopic characteristic variates with color photographic archetypes and line drawings for those characteristics for which no photographs were available.

Chapter 6 introduces the concept of the genetically produced hair type and presents data regarding the geographic region heritage hair types for both scalp and pubic hair.

A glossary of certain terms used in the atlas also is enclosed for the convenience of the reader, and there is an extensive bibliography of publications pertaining to forensic hair examination for the convenience of the reader. The bibliography will provide a starting point for literature searches for the novice hair examiner and a ready reference for the researcher in forensic hair examination, comparison, and identification.

Acknowledgments

The authors gratefully acknowledge the generous donation of time and hair characteristic specimens loaned to them by James G. Bailey, criminalist with the Los Angeles Sheriff's Department Forensic Laboratory and a widely noted authority in forensic hair examination. It is unlikely that this atlas would have been completed in a timely manner without his loan of specimens and his helpful comments during the preparation of the manuscript.

A special thanks is due to David Kahane and Forensic Analytical of Hayward, CA, for funding the photography for the atlas. Thanks are also due to Larry Wayne, research assistant to Michelle Fox, for his help in preparing the many photographic specimens necessary for the completion of the atlas, and to Nicholas Petraco and Richard Bisbing for their input regarding the content of the atlas.

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Introduction to the Atlas of Human Hair Microscopic Characteristics

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1.1 Scope and Function of the Atlas

The atlas was designed to provide photographic examples of the features of human hair seen through the compound microscope which are used by forensic hair examiners in the examination, comparison, and identification of human hairs. Two purposes are served. The photographic illustrations are intended to provide the trainee in forensic hair comparison with a comprehensive set of examples of those characteristics which need to be considered when making a comparison between an evidence hair and exemplar hairs from an individual. In addition, the illustrations will provide a uniform basis for describing the characteristics and their variations by researchers and examiners in differing geographical areas. The documentation of hair characteristics using the scoring system outlined in this atlas will allow researchers and examiners to develop data regarding the frequency of characteristics within the hairs of one or more individuals and the assessment of whether certain hair characteristics are co-dependent. Where for various reasons photographs were not available for inclusion in the atlas, line drawings are presented to illustrate the characteristics described in the tables and in the text.

Although the focus of this atlas is on the microscopic characteristics of human hair, a number of macroscopic characteristics are presented in Chapter 2. The macroscopic characteristics are presented because they are an integral component of the examination and comparison process for hairs.

A glossary of terms used in the atlas is presented in Appendix I. In addition, an extensive bibliography of articles pertaining to forensic hair examination is presented in Appendix II.

This atlas is intended for use by the experienced forensic hair examiner as an aid in research or as a tool in the training of other examiners. This book does not include a discussion of methods and procedures for human hair analysis, nor does it present a protocol for the interpretation of results from human hair comparisons. For a protocol on the examination of hair evidence, see Shaffer.[1]

1.2 Terminology

In the case of human hair, the characteristics which form the basis for hair comparison and identification are well known and are described throughout the literature on forensic hair examination. Although a number of terms have been used to describe the characteristics of human hair (e.g., "characteristic," "feature," "attribute," etc.), the terminology throughout this atlas is confined to the term "characteristic" as the general feature descriptor. Examples of "characteristics" include, but are not limited to, curl, color, pigment distribution, pigment density, cortical fusi, and ovoid bodies. The macroscopic characteristics for human hair are listed in Chapter 2, and the microscopic characteristics are listed in Chapter 3.

The term "variate" is used as the descriptor for the various forms of each macroscopic or microscopic characteristic seen in human hair. For example, the various forms of the characteristic Pigment Distribution are described by the variate terms Uniform, Peripheral, One-sided, Central, and Random. The variates for each characteristic are listed in Chapters 2 and 3.

The term "photographic archetype" refers to the photographs presented throughout this atlas to demonstrate the characteristic variates. An archetype is a model adopted for the specific purpose of establishing a standard of comparison.

Most hair characteristics have continuous variation over the entire range of variation exhibited. Continuous variation means that the difference between one variate and its closest neighbor in terms of similarity is virtually indiscernible. For example, the range of variation for all brown hairs is continuous, where one shade of brown may be indistinguishable from the next closest shade of brown. This assumption that continuous variation exists is due to the large number of hairs on a single scalp and the large number of humans in the world population. This issue of continuous variation within a hair characteristic requires that the variation be partitioned into a number of variate classes. This division into two or more variate classes requires the

adoption of photographic archetypes to define the "variate class limits," or the upper and lower limits of the range of variation for a single variate. For those characteristics having continuous variation, each of the characteristic variate class limits is defined by photographic archetypes. Some hair characteristic variates are determined by measurement (e.g., Maximum Shaft Diameter). For those characteristic variates determined by measurement, no photographic archetypes are presented.

Some of the hair characteristics demonstrate discontinuous variation. Discontinuous variation means that each variate of a characteristic has a recognizable form which is different from the other variates. For example, the characteristic Pigment in Cuticle can be exhibited by the discontinuous variates Present and Absent. For those characteristics with discontinuous variates, the photographic archetypes represent examples of each variate.

The term "class characteristic" refers to a characteristic shared by all members of a class. A class of objects can be defined by a single characteristic or by a combination of characteristics shared by the members of the class. Except in rare circumstances, a class is defined by a combination of these class characteristics (e.g., 38 caliber firearms having rifling with six lands and grooves with a left hand twist, blond human hair, etc.).

The term "individual characteristic" refers to a characteristic that is unique to a single object in a class, or to a class characteristic that ***varies*** in some way from one member of the class to another. This variation in the class characteristic can be combined with other class characteristics which also exhibit variation, so that the ***specific combination of these characteristics' variations*** may be unique within the class of objects. For example, fired bullets have a class of characteristics called "striations," which are the result of the bullet being marked by the interior surface of the barrel as the bullet passes through the barrel. Although a single striation on the bullet cannot be determined to be unique to that barrel, the ***combination*** of the ***occurrence and spatial relationships*** of a number of striations can be determined to be unique to that specific barrel. Thus, the striations are considered to be individual characteristics, since their combination as a set allows for individualization of the fired bullet.

The specific ***combination*** of genetically controlled macroscopic and microscopic characteristic variates observed in a particular hair is termed in this atlas as the "***hair type***." The determination of hair type will allow researchers to develop data to determine the frequency of a hair type within an individual or within a group of individuals. Hair type data may also provide information on whether certain characteristics are co-dependent. The macroscopic and microscopic characteristics used to define the hair type are listed in Chapter 6.

1.3 Individualization of Physical Evidence

The central concept in the forensic science specialty called criminalistics is individualization. Individualization is the cement that binds together all the disciplines in the forensic sciences involving the examination of physical evidence with the aim of identifying the source of an evidence item. That concept applies equally to a fired bullet, a signature on a document, a hair or fiber found on a murder victim, or a bloodstain found at a crime scene. Each discipline may use different techniques to individualize its particular type of physical evidence, but the approach to the individualization process is the same. The concept of individualization requires that a questioned item (an item with a questioned source) must have a combination of class and individual characteristics which agrees with that combination in an item of known source. Some types of physical evidence may be individualized (e.g., fingerprints, fired bullets), while others may be identified only as to the class to which the evidence belongs (e.g., hairs, fibers, glass).

The individualization process is a two-step operation, where the questioned item is first compared to an item of known source to determine if the class characteristics are the same.[2] If they are different, the known source is excluded as a possible source of the questioned item. If the class characteristics are the same, the individual characteristics are then compared. If the individual characteristics are not the same, then the examiner must determine whether the degree of difference observed is equivalent to or exceeds the degree of difference observed when comparisons are made between experimental specimens and known nonsources for the specimens within the same class. If the degree of difference observed exceeds the degree of difference noted in comparisons between experimental specimens and known nonsources, then the known sample may be excluded as a source for the questioned item. If the difference observed does not meet the established criteria for exclusion based on these comparisons between experimental specimens and known nonsources for the specimen, then the known source cannot be excluded as a source for the questioned item. If the individual characteristics are the same, then the known source may be identified as the source of the questioned item where the set of class and individual characteristics, which is the basis for the agreement between the questioned item and known sample, can be shown to be unique within the class. An identification of a known source based on the combination of class and individual characteristics shared between the questioned item and the known item is based on the concept that a ***set*** (i.e., the combination) of class and individual characteristics can be unique to a single object when compared to the entire class of similar objects.

For most types of physical evidence, the assessment of uniqueness of the set of class and individual characteristics which is the same for the questioned and known is accomplished by the examiner through reference to either a database of the frequency of the components of the pattern (as in the assessment of a blood sample's DNA pattern) or by reference to the examiner's experiential database in examining that particular type of physical evidence, as in fingerprints, firearms, questioned writings, etc.[3] The examiner's experiential database is augmented by the study of the literature regarding the individualization of each type of physical evidence and the published experiences of other workers in the same discipline during the examiner's training period. In the microscopic examination of human hair, individualization is rarely possible due to the lack of a reference database for the assessment of uniqueness of the set of characteristic variates (the hair type) for a given hair.

1.4 Numerical Scoring of Hairs

Although the macroscopic and microscopic characteristic variates used by the forensic examiner in the comparison of hairs can be used to distinguish between hairs from different individuals, there has been no systematic attempt to develop data on the frequency of those characteristic variates in study populations. One of the primary purposes of this atlas is to present photographic archetypes which will provide a uniform basis for the generation of data on study populations, so that data from different researchers or examiners can be combined to form a larger database of characteristic variate frequencies.

An innovation of the atlas is the introduction of a numerical scoring system permitting the hair type to be presented as an array of alphanumerical scores. Use of the scoring system will simplify the task of developing frequency data for macroscopic and microscopic characteristics and for the hair types found in a study population. The frequency data developed from the studies will enhance the ability of the forensic hair examiner to evaluate the determination that a questioned hair is similar to known hairs from an individual, both in the examiner's report and in the examiner's testimony in judicial proceedings.

The numerical scoring system is based on photographic archetypes which define the class limits of characteristic variates. The scoring system allows the examiner to express hair type as an array (ordered series) of double-digit numbers with each double-digit number preceded by a letter identifier. The generation of frequency data can thus be accomplished through the use of simple computer programs and will allow researchers to assess the rarity of a particular variate or hair type in the study population.

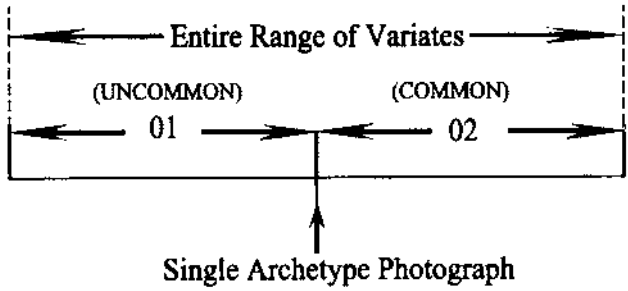

Figure 1.1 Variate class limits for two classes determined by one photographic archetype.

The system by which a human hair characteristic with continuous variation is determined is illustrated in Figures 1.1 and 1.2. Figure 1.1 illustrates the division of a microscopic characteristic into two variate classes with the use of a single photographic archetype. The variate of the study hair is categorized either as being below the archetype (uncommon) or as being equal to or above the archetype (common) with regard to the commonness of the characteristic in the hair. Figure 1.2 illustrates the division of a microscopic characteristic into three variate classes with the use of two archetypes. A study hair's variate is selected depending on whether the variate falls below the first archetype (rare), is equal to the first archetype or between the first and second archetype (common), or is equal to the second archetype or higher than the second archetype (profuse). The same method is used for dividing continuous variation into four or more variate classes. The adoption of three archetypes will split a characteristic into four variate classes. Four archetypes will split a characteristic into five variate classes, and so on.

For those characteristics with discontinuous variation, the variate of the study hair is determined by comparing the study hair to the photographic archetype and selecting which archetype is most similar to the study hair. Those characteristic variates which are determined by measurement are

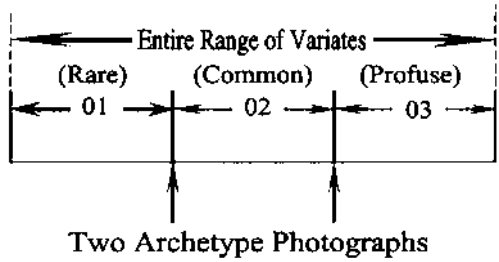

Figure 1.2 Variate class limits for three classes determined by two photographic archetypes.

scored based on the measured value. Once the characteristic variate is determined, a score is assigned to that particular variate. The scores are alphanumeric identifiers which are listed for each characteristic variate in Table 2.1, Table 3.1, and Table 4.1. An illustration of the alphanumeric score generated for the characteristics of a single hair is outlined in Chapter 6.

The examiner should be consistent when determining the variate scoring for a single hair. Note that the scoring of a particular hair may differ when the hair is scored proximally, medially, and distally. For that reason, the examiner or researcher should score the hair in the medial region, at least 2 cm distal to the hair root. In those hairs which vary significantly along the shaft, it may be necessary to describe the hair as a polytype and record three hair types designated by the scores taken at the proximal, medial, and distal areas. The examiner should also be consistent when deciding how to score a particular characteristic variate. The scoring for an observed variate which is too close to one of the variate class limit archetypes to be scored unambiguously should be scored as belonging to the variate class having the higher score. That approach will ensure consistency for scoring from hair to hair by the same examiner and for scoring of the same hair by two or more examiners. Scoring in a consistent manner will allow data from different examiners to be combined.

1.5 Materials and Methods

Many of the hair specimens used for inclusion in the atlas consisted of previously prepared permanent microscope slide mounts from the authors' collections and from the collection of James Bailey of the Los Angeles Sheriff's Department Criminalistics Laboratory. Additional hair specimens were solicited from the authors' friends, associates, and professional colleagues. The hair preparations for the atlas photographs were constructed using a template composed of two 1 ¥ 3 in. microscope slides taped to a stiff matte board with adequate space between the slides to place a third slide between the two (see Figure 1.3). The two side slides (A, B) were covered with double-sided adhesive tape so that segments of the study hair could be anchored temporarily across the surface of the permanent slide (S) in the center. The study hair segments were then taped to the double sided tape on the outside slides so that the resultant slide mount contained serial segments of the study hair with the root at the top, the tip at the bottom, and the consecutive shaft segments between the root and tip ends. After the hair segments were placed on the slide in this manner and mounting medium was added and covered with a cover slip, the mounting medium was allowed to cure, and the hair

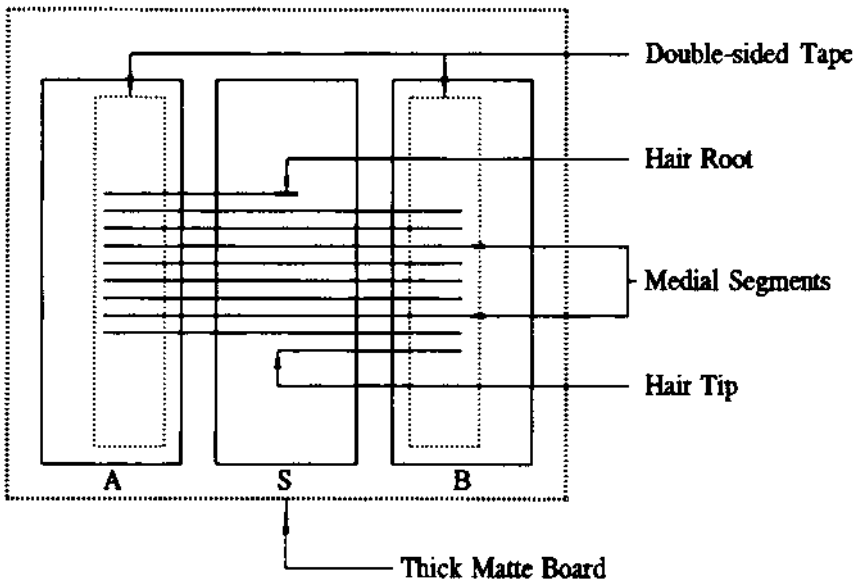

Figure 1.3 Hair slide preparation layout.

segments were trimmed at the edge of the study slide. It was found that this method of hair preparation allowed for an efficient survey of the microscopic characteristics along the length of the hair from the root to the tip. Note that this method of hair preparation is suitable only for research specimens and should not be used for evidential specimens.

Some of the hairs were prepared using mounting medium Accumount™ (Baxter Scientific, McGaw Park, IL), refractive index of approximately 1.500. Other preparations were made using mounting medium Norland Optical Adhesive™ (Norland Products, Inc., New Brunswick, NJ), refractive index of approximately 1.520. The range for refractive index of human hair is approximately 1.543 to 1.554.[4] Selecting a mounting medium with a refractive index close to the range of the refractive index of human hair allows the examiner to more easily observe the microscopic characteristics without the interference of contrast. A mounting medium with a refractive index in the range of approximately 1.50 to 1.55 is recommended.

Photographs of the characteristic variates were taken through a trinocular light microscope using Kodak Ektrachrome® (Eastman Kodak, Rochester, NY) Tungsten film, ASA 160. The use of tungsten slide film has a number of advantages over other film types. The principal advantages of using tungsten slide film include the ability to convert the slide image to a photographic print or a scanned image, the availability of the slides for use as teaching aides, the ease with which the examiner or researcher can achieve color

balance with this film type, and the lack of light intensity loss experienced due to the necessity for color filters with other types of film. The microscope settings were kept constant (e.g., Kohler illumination) for all microphotography. The majority of photographs were taken with a 40¥ objective and a 2.5¥ photo ocular. Those characteristics needing higher magnification for proper viewing of the resultant slide were taken using a 100¥ oil immersion objective with the 2.5¥ photo ocular. Photographs taken at lower magnifications were performed using either a 4¥, a 10¥, or a 20¥ objective with the 2.5¥ photo ocular.

Human Hair Macroscopic Characteristics

2

Although this atlas was designed primarily to present photographic archetypes for the variates of microscopic hair characteristics, a description of the macroscopic characteristics of hair form, degree of curl, and length have been included (Table 2.1). In addition to hair form, curl, and length, the examination of hair color at the macroscopic level can also be an important part of a hair comparison. However, the authors have chosen to present color as determined microscopically (see Chapter 3).

2.1 Hair Form

Hair form refers to the general appearance of the hair with regard to curl. A definitive measurement of curl is discussed in Section 2.2. For the purpose of describing hair form, the terms Straight, Curved, Wavy, Loose Curl, and Tight Curl are presented. For clarification purposes, some of the definitions for those terms include reference to data generated by the Degree of Curl Template presented in Section 2.2. Straight hair is defined in this atlas as hair with no curvature, or hair that has a curvature less than that of a circle having a diameter of greater than 80 cm (see Degree of Hair Curl below). Curved hair is defined here as hair that has a slight curvature but does not exhibit waviness or does not curl back upon itself to form a circle when the hair is placed on a flat surface. Wavy hair is defined as hair that has curvature that changes its direction to produce a sinuous wave form and does not curve back upon itself to form circle-like figures when placed on a flat surface. Curly hair is defined as hair that curls back upon itself to form circles or circle-like forms when placed on a flat surface. It is divided into Loose Curl and Tight Curl. The term Loose Curl is used to describe hair that forms

Table 2.1 Macroscopic Characteristics of Human Hair[a]

01.	Hair Form				
	A00 Straight	A01	Curved	A02	Wavy
	A03 Loose Curl	A04	Tight Curl		
02.	Degree of Curl[b]				
	B00 > 80	B01	<= 80	B02	<= 40
	B03 <= 20	B04	<= 10	B05	<= 5
	B06 <= 3	B07	<= 2		
	B08 <= 1	B09	<= 0.5		
03.	Shaft Length				
	C01 < 2.5 cm	C02	2.5 -> 7.5 cm	C03	7.5 -> 15 cm
	C04 15 -> 30 cm	C05	> 30 cm		

[a] Table 2.1 adapted from Tables 1 and 2, Ogle, R. R., Jr., Individualization of human hair: the role of the hair atlas, *Microscope*, 46(1), 19, 1998. With permission.

[b] Centimeter of circle described by arc of hair curl, judged by comparison to template.

circle-like figures with a degree of curl from 04 to 06 on the Degree of Curl Template (Figure 2.1). The term Tight Curl describes hair that has a curl from 07 to 09 on the Degree of Curl Template (Figure 2.1).

2.2 Degree of Hair Curl

A template based on the measurement of curvature by Bailey and Schliebe[5] is presented, which can be used to determine the degree of curl present in a study hair (see Figure 2.1). The template was designed so that a study hair can be placed between two clear plates and set over the template. The degree of curvature of the hair can be readily determined by comparing the hair to the curvatures of known circle diameters. The hair can thus be scored by reference to the numerical values indicated on the curl template (Figure 2.1). For those situations in which more than one measured curvature value applies to a single hair, the value representing the maximum curl (the smallest diameter) should be documented.

The shape of the cross-section is related to the natural curl of the hair.[6] Naturally straight hairs have a cross-sectional shape that is near circular. Naturally curly hairs have a cross-sectional shape that is oval to flattened, depending on the degree of curl. The correlation between natural degree of curl and cross-sectional shape indicates that cross-sectional shape and degree of curl do not necessarily represent two distinct, independent variates. The use of this atlas in developing correlation data for the macroscopic and microscopic hair characteristics may help clarify the relationship between degree of hair curl and cross-sectional shape.

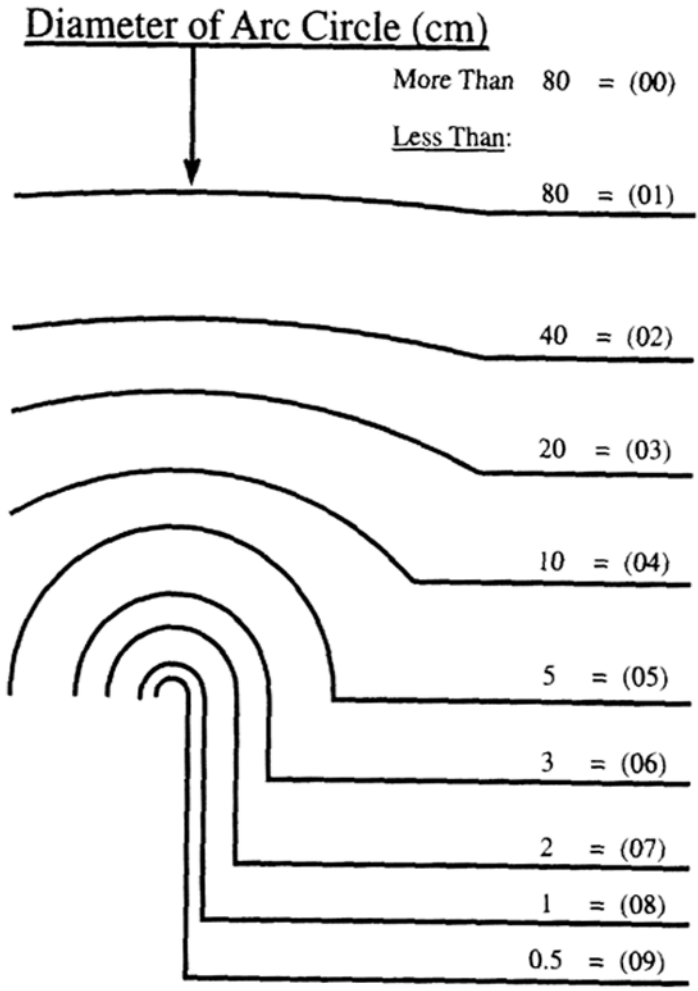

Figure 2.1 Hair curvature measurement template.

2.3 Shaft Length

The shaft length is defined as the entire length of the hair, and it is expressed in centimeters, although the examiner may convert the length into inches in parentheses if desired. The shaft length is determined by manually straight-

ening the hair next to a ruler. The shaft length may be an important characteristic if the hairs from a known source and the questioned hairs are collected within a short time frame. If some time has elapsed between the deposition of the questioned hair(s) and the collection of known hairs from a suspected source, the possibility of significant hair growth or a haircut by the suspected source individual should be considered when evaluating a comparison of length. Examination of the distal hair shaft tips may provide evidence of the presence or absence of a recent haircut, which would impact the significance of the hair shaft length as a comparison characteristic. Shaft length is determined by simple measurement and therefore is not represented in the photographic archetypes.

Human Hair Microscopic Characteristics

3

This chapter presents a description of each microscopic characteristic that plays an important role in the forensic comparison of human hair. The microscopic hair structures useful to the forensic hair examiner include the cuticle, the medulla, and the cortex. The cuticle consists of overlapping scales which cover the hair shaft. The medulla is the canal of air or liquid-filled cells in the center of the cortex. The cortex is the main body of the hair which consists of keratinized fibers oriented parallel to the long axis of the hair and which contains a number of inclusions that are outlined and described throughout this chapter. Table 3.1 lists and describes those microscopic characteristics of the human hair that are of value to the forensic hair examiner, with a description of each characteristic and its variates. The photographic archetypes that demonstrate each microscopic characteristic and its variates are located in Chapter 5.

3.1 Color

The dominant human hair characteristic useful for forensic hair comparisons, both macroscopically and microscopically, is hair color. The color of the hair depends on the pigment present, the surface transparency, and the reflectivity of the hair.[7] There are two observed pigments that account for the color of human hair. Melanin is the brown pigment, and phaeomelanin is the red pigment. Pigment granules of phaeomelanin are not observable with light microscopy owing to the small size of the granules.[8] For a detailed discussion of the chemistry, structure, and physiology of the various melanins, see Cesarini.[9]

Table 3.1 Microscopic Characteristics of Human Hair[a]

01.	Color:					
			Colorless			
	D00	Color Absent (White/Gray Hair)				
			Blond			
	D01	Light	D02	Light to Medium		
	D03	Medium to Dark	D04	Dark		
			Golden Brown			
	D11	Light	D12	Light to Medium		
	D13	Medium to Dark	D14	Dark		
			Brown			
	D21	Light	D22	Light to Medium		
	D23	Medium to Dark	D24	Dark to Opaque		
	D25	Opaque				
			Gray Brown			
	D31	Light	D32	Light to Medium		
	D33	Medium to Dark (Black)				
	D34	Dark (Black) to Opaque				
			Red			
	D41	Light	D42	Light to Medium		
	D43	Medium to Dark	D44	Dark		
			Red Brown			
	D51	Light	D52	Light to Medium		
	D53	Medium to Dark	D54	Dark		
			Other			
	D61	Other (Hair color not found in above color scheme) Specify Color				
02.	Pigment Density					
	E00	Absent	E01	Light		
	E02	Light to Medium	E03	Medium to Heavy		
	E04	Heavy to Opaque	E05	Opaque		
03.	Pigment Granule Size					
	F00	Absent/Obscured	F01	Fine	F02	Coarse
04.	Pigment Distribution					
	G00	Absent	G01	Uniform		
	G02	Peripheral	G03	One-sided		
	G04	Central	G05	Random		
	G06	Other				
05.	Pigment Aggregate Shape					

Table 3.1 Microscopic Characteristics of Human Hair[a] (continued)

	H00	Absent/No Aggregates	H01	Streaked		
	H02	Clumped	H03	Other		
06.	Pigment Aggregate Size					
	I00	Absent/No Aggregates	I01	Small Streaks		
	I02	Medium Streaks	I03	Large Streaks		
	I04	Small Clumps	I05	Medium Clumps		
	I06	Large Clumps	I07	Other		
07.	Medulla Continuity					
	J00	Absent/Obscured	J01	Continuous		
	J02	Interrupted	J03	Fragmentary		
	J04	Continuous/ Interrupted	J05	Continuous/ Fragmentary		
	J06	Interrupted/ Fragmentary				
	J07	Continuous/Interrupted Fragmentary				
08.	Medulla Opacity					
	K00	Absent/Obscured	K01	Opaque		
	K02	Translucent	K03	Opaque/ Translucent		
09.	Cuticle Thickness					
	L01	Thin	L02	Thick		
	L03	Varies	L04	Not Apparent		
10.	Inner Cuticle Margin					
	M01	Indistinct	M02	Distinct	M03	Varies
11.	Outer Cuticle Scale Profile					
	N01	Smooth	N02	Serrated	N03	Ragged
	N04	Looped	N05	Other		
12.	Cuticle Surface					
	O01	Normal	O02	Damaged		
13.	Pigment in Cuticle					
	P01	Absent	P02	Present		
14.	Cortical Texture					
	Q00	Absent	Q01	Present	Q02	Obscured
15.	Cortical Fusi					
	R00	Absent	R01	Root Only	R02	Rare
	R03	Common	R04	Profuse	R05	Obscured
16.	Ovoid Bodies					
	S00	Absent	S01	Few	S02	Many
	S03	Obscured				
17.	Root Growth Stage					
	T00	Absent	T01	Anagen		
	T02	Catagen	T03	Telogen		
18.	Distal Tip Characteristics					
	U01	Natural Taper	U02	Rounded Taper		

Table 3.1 Microscopic Characteristics of Human Hair[a] (continued)

	U03	Square Cut/Straight Edge	U04	Angled Cut/Straight Edge		
	U05	Square Cut/Rounded Edge	U06	Angled Cut/Rounded Edge		
	U07	Split	U08	Frayed		
	U09	Crushed	U10	Singed		
	U11	Broken	U12	Other		
19.	Maximum Shaft Diameter					
	V01	Fine (< 40 microns)	V02	Medium (40 to 80 microns)	V03	Coarse (> 80 microns)
20.	Shaft Aberration					
	W00	Normal	W01	Buckling	W02	Shouldering
	W03	Splitting	W04	Undulating	W05	Convoluting
21.	Hair Treatments					
	X00	Absent/Not Apparent	X01	Dyed		
	X02	Bleached	X03	Permed		
	X04	Combination	X05	Other		
22.	Hair Diseases and Disorders					
	Y01	Trichorrhexis Nodosa	Y02	Trichorrhexis Invaginata		
	Y03	Trichoschisis	Y04	Pili Annulati		
	Y05	Monilethrix	Y06	Pili Torti		
	Y07	Trichonodosis	Y08	Cartilage Hair Hypoplasia		
	Y09	Other				
23.	Miscellaneous Characteristics					
	Z01	Double Medulla	Z02	Streaky Medulla		
	Z03	Gapping Pigment	Z04	Debris Present		
	Z05	Trailing Ovoid Bodies	Z06	Other		
24.	Insect, Arachnid, and Fungal Presence and Damage					
	AA01	Lice/Louse Eggs	AA02	Insect/Arachnid Damage		
	AA03	Fungal Damage	AA04	Other		

[a] Table 3.1 adapted from Tables 1, 2, and 4, Ogle, R. R., Jr., Individualization of human hair: the role of the hair atlas, *Microscope*, 46(1), 19, 1998. With permission.

The hair colors and shades presented in this atlas were determined using a comparison light microscope. The authors have grouped the variates for hair color into the following: Blond, Golden Brown, Brown, Gray Brown, Red Brown, Red, and Other. Each color is presented in Chapter 5 as a series of three archetype photographs that partition the color into four ranges of shades of that color. When determining the color and shade of a study hair,

the examiner must recognize the continuous range between each photographic archetype. For example, there is a continuous range of colors between Blond and Golden Brown, as well as a continuous range of shades between Light Golden Brown and Medium Golden Brown. The color of the study hair is determined by selecting the color archetype series that is most similar to that of the study hair. The shade of the study hair is then determined using the selected color archetype series (the series of three photographs that partitions the ranges of shades for the selected color). The variates for each color shade include Light, Light to Medium, Medium to Dark, and Dark and are partitioned using three photographic archetypes. The authors acknowledge that the palette of colors and shades presented in this atlas may be limited. Some naturally colored hairs and some artificially colored hairs may not be represented here. Such hairs should be scored as the variate Other. Future research into hair pigments may refine this color scheme considerably.

The color and shade of a hair that has an oval or flat cross-sectional shape may vary depending on the orientation of the hair under the microscope. Hairs with oval or flat cross-sectional shapes that are oriented on their side might appear darker. As a general rule, all microscopic characteristics should be determined with the hair oriented such that the maximum shaft diameter (i.e., the maximum diameter of the cross-sectional shape) is being observed. Other characteristics that might be affected by the orientation of the hair include Pigment Density (Section 3.2) and Pigment Distribution (Section 3.4).

3.2 Pigment Density

Pigment density refers to the abundance of pigment granules observed using light microscopy. Pigment density is a continuous variate when applied to the entire human population. Thus, the number of possible variations in the density of human hair likely approaches infinity. The archetypes established by the authors for the purposes of this atlas divide pigment density into the following variates: Absent, Light, Light to Medium, Medium to Heavy, Heavy to Opaque, and Opaque. Those variates are partitioned using three photographic archetypes; a fourth archetype represents an Opaque hair. The photographic archetypes are presented in Chapter 5. Human hair researchers may wish to add more variates to this characteristic when studying small populations that might demonstrate pigment density variation within only one of the variates defined here.

The density of pigment granules appears to be highly correlated with microscopic hair color and therefore may represent a redundant hair characteristic in the context of forensic hair comparisons. The development of frequency data may more clearly define the relationship between pigment

density and hair color. It is clear, however, that the correlation between hair color and pigment density is very high. One might say that color is in fact the result of the ensemble of pigment size, density, and distribution (along with the optical properties of the cuticle and cortex).

3.3 Pigment Granule Size

Pigment granule size refers to the size of the individual melanin pigment granules as judged by comparison to the archetypes. The variates of pigment size include Absent/Obscured, Fine, and Coarse. Examples of Fine and Coarse pigment granules are presented in Chapter 5. The term Absent/Obscured can refer to either the absence of pigment (e.g., white or gray hairs) or the inability to resolve individual pigment granules using light microscopy. The inability to resolve individual pigment granules may be due to the small size of the granules (e.g., phaeomelanin pigment) or the obscured effect caused by heavy pigmentation when looking at the hair in a longitudinal mount (e.g., opaque hair). If the examiner deems it necessary, the pigment granule size of heavily pigmented hairs can be observed either by cross-sectioning the hair or by slicing the hair lengthwise into tapering sections. The pigment granules of hair containing phaeomelanin pigment (red hair) may be seen using scanning electron microscopy.[10] Hairs containing only phaeomelanin pigment will probably be scored as Absent/Obscured (not visible) with regard to pigment size when viewed using light microscopy.

With further use of the scanning electron microscope, researchers may want to designate variate categories based on measured sizes rather than on comparative sizes. That approach may add additional variate categories for the researcher, or it may indicate that the variates listed here suffice for classification purposes.

3.4 Pigment Distribution

Pigment distribution refers to the distribution and concentration of the pigment granules in various areas of the hair shaft. The variates for pigment distribution are Absent, Uniform, Peripheral, One-sided, Central, Random, and Other. Photographic archetypes illustrating each form of pigment distribution are presented in Chapter 5. The term Absent refers to the absence of pigment in the hair shaft (e.g., white or gray hair). Uniform refers to pigment that is evenly distributed across the cortex of the hair. Peripheral refers to pigment that is concentrated at the outer edges of the shaft. One-sided refers to pigment that is concentrated on one side of the shaft. Central refers to pigment that is concentrated (or appears to be concentrated) in the

center of the shaft. Random refers to pigment that is found in greater concentrations in some areas of the shaft and in lesser concentrations in other areas of the shaft, with no recognizable pattern. Hairs that contain sparse amounts of pigment (with random areas of the cortex completely absent of pigment) would be categorized as having a random pigment distribution. The term Other refers to pigment distribution that does not fit any of those variate categories.

Pigment distribution normally can be judged adequately by viewing the hair shaft in the longitudinal mount. The orientation of the hair should be such that the maximum shaft diameter (i.e., the maximum cross-sectional shape) is being observed. In the case of blond or red hair, individual pigment granules may not be resolved using light microscopy, and the pigment may appear to be more concentrated centrally, owing to the difference between the length of the light path through the central portion of the shaft and the length of the light path nearer the edge of the shaft. When scoring the pigment distribution for those hairs, the examiner should categorize the hair as having central distribution, even though the distribution may be an artifact resulting from optical effects. Some examiners may find it necessary to examine a cross-section of the shaft to determine and document the actual pigment distribution.

3.5 Pigment Aggregate Shape

Pigment aggregate shape refers to the appearance of the pigment granules when they are concentrated in a mass that has a recognizable form. The variates for pigment aggregate shape are Absent/No Aggregates, Streaked, Clumped, and Other. Photographic archetypes illustrating each variate of pigment aggregate shape are presented in Chapter 5. The variate Absent/No Aggregates can refer to either the absence of pigment (e.g., a white or gray hair) or a pigmented hair that exhibits no aggregation. Aggregated pigment granules may appear streaked or clumped, both of which can be judged by reference to the archetypes presented in the atlas. In those hairs for which aggregation exists but cannot be clearly categorized as Streaked or Clumped (e.g., opaque hair) or for those hairs that appear to have a mixture of streaked aggregates and clumped aggregates, the hairs should be categorized as Other.

3.6 Pigment Aggregate Size

Pigment aggregate size refers to the size of the aggregates as judged by comparison to the archetypes. Aggregate size is described as Absent/No Aggregates, Small Streaks, Medium Streaks, Large Streaks, Small Clumps, Medium

Clumps, Large Clumps, and Other. The variates are partitioned using the four photographic archetypes presented in Chapter 5. The variate descriptor Absent/No Aggregates can refer to either the absence of pigment or the absence of pigment aggregation. The aggregate size is determined by comparison to the archetypes. As with the variates for pigment aggregate shape, there may be an intergrade in a particular study hair that is too close to the archetype to assess whether the study hair falls in the variate class above or below the archetype. If that happens, the examiner should follow the convention of categorizing the study hair variate as belonging to the higher variate class. In those hairs for which aggregation exists but cannot be clearly categorized in one of the listed variates, the variate Other would apply.

3.7 Medulla Continuity

Medulla continuity refers to the nature of opaque and translucent forms (see Section 3.8) of the medulla from the proximal end to the distal end of the hair shaft. The medulla form in human hairs can be described as amorphous, since the medulla normally does not have a discernible internal pattern such as the complex, structural patterns found in many nonhuman hairs. The continuity of a medulla along the shaft does, however, often have a discernible pattern. The primary continuity patterns seen in human hair medullas consist of Absent, Continuous, Interrupted and Fragmentary, or combinations of those patterns. These terms refer to both the translucent and the opaque forms of the medulla. Photographic archetypes illustrating each medulla continuity variate are presented in Chapter 5. The term Absent refers to hairs with no visible medulla, including those hairs with no visible medulla due to heavy pigmentation. The term Continuous refers to a medulla that extends along the shaft with no interruption. The term Interrupted refers to the same condition described by Hicks as Discontinuous. Hicks defines the term Discontinuous (Interrupted) as the condition where the lengths of the visible medulla are greater than the lengths of the indiscernible portions of the medulla, and he defines the term Fragmentary as the condition when the lengths of the indiscernible portions of the medulla exceed the lengths of the discernible portions.[11] For purposes of this atlas, a discernible portion is defined as a visible medulla portion regardless of whether it is opaque or translucent.

When combinations of the medulla continuity patterns are observed in a hair, the hair is scored as either Continuous/Interrupted, Continuous/Fragmentary, Interrupted/Fragmentary, or Continuous/Interrupted/Fragmentary. It should be noted that a medulla (the medullary cells) may not be visible (Absent), or it may be visible regardless of whether it is opaque or

translucent. In some hairs, a "continuous" medulla may have portions that are opaque and portions in which the medullary cells are visible and translucent. Traditionally, some examiners have judged the continuity of the medulla based on the continuous nature of the opaque form only. The approach suggested here is to judge the continuity of the medulla based on both the opaque and translucent forms.

3.8 Medulla Opacity

Medulla opacity refers to the appearance of the medulla as viewed with transmitted light in the compound light microscope. The variates for medulla opacity include Absent, Opaque, Translucent, and Opaque/Translucent. Photographic archetypes illustrating each form of medulla opacity are presented in Chapter 5. The term Absent refers to hairs with no visible medulla, including those hairs in which the medulla is obscured due to heavy pigmentation. When the medulla is filled with air, it will appear opaque under a microscope. When the medulla is filled with liquid, it will appear translucent. Some hairs contain a medulla that has both opaque and translucent segments along their shafts. These hairs are scored as Opaque/Translucent.

3.9 Cuticle Thickness

The cuticle is the layer of overlapping scales that forms the outer layer of the hair. The variates for cuticle thickness are based on measurement and include the terms Thin, Thick, Varies, and Not Apparent. Measurement of the cuticle should be performed at the maximum shaft diameter and is determined by measurement with an ocular micrometer calibrated with a stage micrometer. The term Thin refers to a cuticle thickness of less than 2.5 μm. The term Thick refers to a cuticle thickness of 2.5 μm or greater. The term Varies refers to those hairs where the cuticle thickness varies along the shaft at or near the widest diameter. The term Not Apparent refers to cuticles that are not easily measured due to an indistinct inner cuticle margin (see Section 3.10).

3.10 Inner Cuticle Margin

The inner cuticle margin refers to the border between the cuticle and the cortex. The variates of the inner cuticle margin consist of Indistinct, Distinct, and Varies as viewed longitudinally. Photographic archetypes illustrating each variate of inner cuticle margin are presented in Chapter 5. The term Indistinct refers to the condition when the inner margin of the cuticle may

not be visible or is not well defined. The term Distinct refers to the condition when the border between the cuticle and the cortex is readily apparent and is well defined. The term Varies refers to those hairs with an inner cuticle margin that varies in its distinctness due to a variation in pigment density along the inner margin. There appears to be a correlation between pigment density and the distinctness of the inner cuticle margin. Heavily pigmented hairs tend to have relatively distinct margins, and lightly pigmented hairs tend to have relatively indistinct margins. Experimental data with regard to establishing the correlation coefficient for these two variates can be accomplished for study populations by a researcher.

3.11 Outer Cuticle Scale Profile

The term Outer Cuticle Scale Profile refers to the pattern of the outermost edge of the cuticle jutting from the hair surface when the hair is viewed in the longitudinal mount. The condition of the cuticle profile can be natural or the result of environmental factors (e.g., hair treatments). The variates of the cuticle profile are Smooth, Serrated, Ragged, Looped, and Other. Photographic archetypes illustrating each variate of cuticle profile are presented in Chapter 5. The term Smooth refers to a cuticle profile that is even or flat. The term Serrated refers to a cuticle profile that is "saw-toothed." The term Ragged refers to a cuticle profile that is uneven and irregular. The term Looped refers to the condition when the scales are curved at their distal edges so that they cup, or arch, at the edge of the shaft. Looped scales can trap air below the curved portion, giving the appearance of a dark band between the scale and the shaft. The variate Other refers to either hairs that have a combination of cuticle conditions or hairs that have a cuticle profile that cannot be categorized as Smooth, Serrated, Ragged, or Looped.

3.12 Cuticle Surface

Cuticle Surface refers to the condition of the scales on the surface of the cuticle as seen in a longitudinal air mount or in a scale cast prepared by the method of Ogle[12] or Hicks.[13] The cuticle surface variates described here are Normal and Damaged. Photographic archetypes illustrating Normal and Damaged cuticle surfaces are presented in Chapter 5. The term Normal refers to a cuticle surface that does not have any discernible damage when viewed in the compound microscope. The term Damaged refers to a cuticle surface that has discernible damage due to hair treatments or to damage from environmental effects.

3.13 Pigment in Cuticle

The variates for pigment in cuticle include Present or Absent. Photographic archetypes illustrating each are presented in Chapter 5. The presence of melanin pigment granules in the cuticle appears to be correlated with pigment density. The presence of pigment in the cuticle is more commonly observed in heavily pigmented hairs. Experimental data with regard to establishing the correlation coefficient for these two variates can be accomplished for study populations by a researcher.

3.14 Cortical Texture

Cortical texture refers to the appearance of the cortex as viewed in a longitudinal mount. The variates for cortical texture are Absent, Present, and Obscured. Photographic archetypes illustrating each variate for cortical texture are presented in Chapter 5. The cortex may have no apparent texture (Absent), it may demonstrate a streaky texture (Present), or the ability to observe the cortical texture may be obstructed due to heavy pigmentation (Obscured). The "streaky" nature of the cortical texture may be due to relatively sizeable bundles of fibers that are readily appreciated when the hair is viewed longitudinally in the microscope. Although the authors have described cortical texture to be streaked, the variate Present may be applied to other observed texture forms as well. Examiners should be aware that stopping down the substage condenser may allow the texture of the cortex to be more easily observed.

3.15 Cortical Fusi

The cortical fusi are small, fusiform (spindle-shaped) bodies that lie between the cortical cells of the cortex.[14] They are commonly found in the hair root and the immediate proximal portion of the hair shaft. Distally, they are more uncommon and usually exhibit a shrunken appearance. The variates are defined here as Absent, Root Only, Rare, Common, Profuse, and Obscured. The variate Absent refers to the absence of cortical fusi. The variate Root Only refers to hairs that contain cortical fusi in the root only or hairs that contain cortical fusi in the root and in the proximal end of the hair only. The variates Rare, Common, and Profuse refer to the concentration of cortical fusi as they exist along the shaft of the hair in the medial and distal regions. Those variates are partitioned using the two photographic archetypes presented in Chapter 5. The term Rare refers to a low concentration of cortical

fusi along the shaft. The term Common refers to a greater concentration of cortical fusi along the shaft, and the term Profuse refers to a high concentration of cortical fusi along the shaft. The concentration of cortical fusi is not presented here as a quantitative measurement but is determined in a study hair by comparison to the photographic archetypes. The variate Obscured refers to the inability to observe the presence of cortical fusi due to obstruction by heavy pigmentation (e.g., opaque hair).

3.16 Ovoid Bodies

Ovoid bodies exist in the hair cortex and are aggregations of pigment that can have a spheroidal or oblong shape. Ovoid bodies can range in diameter from 3 to 20 μm; however, this size range may not be all inclusive. The variates for ovoid bodies relate to the abundance of ovoid bodies present in the hair shaft. The variates for ovoid bodies include Absent, Few, Many, and Obscured. The term Absent refers to the absence of ovoid bodies. The term Few refers to the presence of a small number of ovoid bodies in the shaft. The term Many refers to the presence of numerous ovoid bodies in the shaft. To maintain consistency in scoring, the authors recommend the following quantitative technique: Scan the subject hair from end to end at 200¥ (other magnification levels may be used). Determine the number of ovoid bodies for each field of view. Determine the average number of ovoid bodies per field of view by dividing the total number of ovoid bodies counted by the number of fields of view. If the average number counted per field is less than 10, the hair should be categorized as Few. If the average number counted per field is 10 or more, the subject hair should be categorized as Many.

This quantitative technique may not partition hairs containing ovoid bodies into two equally sized groups, but it will allow some consistency between examiners. Research on the abundance of ovoid bodies observed in a given study population of hairs may reveal either that this quantitative evaluation does not provide useful comparative information and a different quantitative technique is more appropriate or that the quantitative evaluation of ovoid bodies is not feasible.

One limitation to this quantitative technique may be associated with length. If a portion of the shaft is broken or cut, the average number of ovoid bodies observed in the remaining portion may result in a different score; therefore, examiners may need to consider length as a factor when comparing the abundance of ovoid bodies in a questioned hair to hairs from a known source. The variate Obscured refers to the inability to observe the presence of ovoid bodies due to obstruction by heavy pigmentation (e.g., opaque hair).

3.17 Root Growth Stage

The characteristic variates of the hair root growth stages represent the growth stage of the hair at the time of its removal or loss from the body and include Absent, Anagen (active growth phase), Catagen (transitional phase between anagen and telogen phases), and Telogen (terminal stage prior to the hair falling out of the hair follicle). The variate Absent refers to those hairs that do not have a root. A hair pulled from the scalp or pubic region during the Anagen phase will have an epithelial sheath adhering to an elongated, pigmented root. A hair pulled during the Catagen phase may have a slightly enlarged root and may have some bits of epithelial tissue adherent. The Catagen phase is a transitional phase, and the root form may vary depending on whether the phase of a study hair is closest to the Anagen phase or the Telogen phase. A hair pulled or fallen from the scalp or pubic region during the Telogen phase typically has an enlarged root bulb that lacks pigment, has little or no adherent epithelial tissue, and may contain an abundance of cortical fusi. Photographic archetypes illustrating the Anagen phase and the Telogen phase are presented in Chapter 5. The growth phase of the hair root may assist in an assessment of whether or not the hair has been forcibly removed. The presence of epithelial tissue on a root plays an important role in hair examination, owing to the ability to analyze the DNA present in the nuclei of the adherent epithelial cells from the follicular tissue. For a general discussion of the morphology and forensic significance of human hair roots, see the article by Petraco et al.[15] For a discussion of DNA analysis of human hair roots as it pertains to growth stages, see Linch et al.[16]

3.18 Distal Tip Characteristics

The characteristic variates of the distal hair tip may relate to the grooming history of the hair and include Natural Taper, Rounded Taper, Square Cut/Straight Edge, Angled Cut/Straight Edge, Square Cut/Rounded Edge, Angled Cut/Rounded Edge, Split, Frayed, Crushed, Singed, Broken, and Other. Photographic archetypes illustrating each variate of distal tip are presented in Chapter 5. The shape of the tip may represent whether or not the hair has been cut and the type of haircut received by the individual. It also is an indication of whether or not the haircut was recent. A tapered tip may indicate that no cutting has occurred. The angle and condition of a cut tip may indicate the type of haircut received. The presence of a sharp cut edge vs. a rounded cut edge may indicate whether there was a time interval between the time the hair was cut and the time of its separation from the

body. Frayed and Split tips typically have a longitudinal separation of the hair shaft. A Crushed tip typically has a widened shaft. A Singed tip is typically charred, brittle, exhibits vacuoles (cavities in the cortex) in the damaged area, and may have a yellow cast. A Broken tip may take on a number of forms, and the examiner should be aware that Broken tips can sometimes appear like Square Cut tips. Examination and comparison of hair tip variates may strengthen the linkage of a questioned hair to a known specimen when the same variates are seen in both the known and questioned hair samples.

3.19 Maximum Shaft Diameter

The maximum diameter of the hair shaft is determined by measurement with an ocular micrometer calibrated with a stage micrometer. The Maximum Shaft Diameter is the widest diameter along the shaft axis (when scanning from root to tip) and the widest cross-sectional diameter. For example, the cross-section of a curly hair is usually oval or flat. It is the widest dimension of the oval or flat cross-sectional shape that should be considered when measuring the Maximum Shaft Diameter. The diameter variates are defined as Fine (less than 40 microns), Medium (40 to 80 microns), and Coarse (more than 80 microns). Since simple measurement accurately categorizes this variate, there are no photographic archetypes presented.

3.20 Shaft Aberration

Shaft aberration refers to a departure from the "normal" hair shaft, which usually has a relatively uniform diameter from the root to an area near the tip and has a relatively smooth exterior without abrupt changes as seen in the longitudinal mount. Most shaft aberrations occur naturally, but some can result from hair treatment, environmental factors or disease. The variates for shaft aberration include Normal, Buckling, Shouldering, Splitting, Undulating, and Convoluting. Photographic archetypes illustrating each form of shaft aberration are presented in Chapter 5.

Shaft aberration typically is seen in pubic hairs; however, some shaft aberrations are also associated with beard hair and with the scalp hair of individuals with African heritage. The variate Absent indicates that the hair shaft has no disruption. Buckling is an abrupt bend in the shaft with or without a twist. Shouldering refers to a condition in which one side of the hair is thicker, causing a shoulder along the shaft. Shouldering is best observed in a cross-sectional mount, but it may be detected in the longitudinal mount by focusing through the hair and observing the thickness of the shaft. Splitting refers to a split of the medial portion of the shaft

(that does not include splitting at the ends). Undulating refers to a shaft that demonstrates true diameter variation along the length of the hair, causing the edges of the shaft to take on a wave form. Convoluting refers to a twisted hair. A convoluting hair typically has an oval or flat cross-section. In a longitudinal mount, the diameter of a convoluting hair may appear to vary, when in reality, the diameter may be constant and the apparent diameter variation is due to twisting.

3.21 Hair Treatments

Hair treatments can consist of methods to curl, straighten, bleach, and dye the hair. These treatments may or may not cause damage to the hair cuticle and shaft. The observation that a questioned hair and known hairs have received the same treatment may add to the strength of a hair comparison, but the widespread use of hair treatments may also limit the significance of the correspondence. The variates for hair treatments include Absent/Not Apparent, Dyed, Bleached, Permed, Combination, and Other. Photographic archetypes illustrating examples of each hair treatment are presented in Chapter 5. The variate Absent/Not Apparent refers to hairs that appear to have had no treatment with regard to color and curl. The variate Dyed refers to hairs that show evidence of artificial coloring. The variate Bleached refers to hairs that have been treated to remove the natural hair color. The variate Permed refers to hairs that have been treated to alter the natural curl. The variate Combination refers to hairs that have been treated using more than one of the previously discussed treatment methods (e.g., some hairs may have been bleached and subsequently dyed during the same treatment process). The variate Other refers to hairs that appear to be treated, but the observed treatment cannot be categorized as dyed, bleached, or permed.

The result of some treatments may be apparent using light microscopy, while others are not as easily detected. A hair that has been dyed may be apparent by the presence of a demarcation line, or a sharp boundary between the treated portion of the hair and the naturally pigmented newly grown portion. A dyed hair may also exhibit the dye color in the cuticle. A dyed hair also will be apparent by the uniformity of the color distribution. Some hair examiners may recognize a dyed hair based on their observation that the color of the subject hair is not typical of naturally colored hair.

The bleaching of hair may result from an artificial bleaching process, or it may result from natural exposure to the sun. A hair that has been bleached from exposure to sun is often referred to as a solar-bleached hair. A bleached hair may be recognized by the presence of a demarcation line between the treated portion and the naturally pigmented newly grown portion. The

bleached portion may contain no pigment granules, or it may contain significantly fewer pigment granules than the natural portion. The demarcation line of solar-bleached hair typically is not as distinct as the demarcation line of artificially bleached hair. Repeated dyeing and bleaching of a hair may result in several lines of demarcation that might render a hair as being unusual, resulting in a hair comparison that might have greater significance.

Permanent waved hairs sometimes may have buckles or bends in the hair shaft due to the use of perm curlers. These buckles may present themselves at roughly even intervals along the hair shaft due to the manner in which the hair is wrapped around the curler. Artificially straightened hairs sometimes may be recognized by the simple observation that a straight hair has a cross-sectional shape (e.g., oval, flat) that is more consistent with curly hair.

3.22 Hair Diseases and Disorders

Table 3.1 lists some hair diseases and hair disorders found in human hair. Hair diseases and disorders are very rare, and their presence in both a questioned hair and a known hair sample in forensic examinations may strengthen considerably the opinion that the questioned hair could have come from the same individual as the known specimen. The hair diseases listed in Table 3.1 are Trichorrhexis Nodosa, Trichorrhexis Invaginata, Trichoschisis, Pili Annulati, Monilethrix, Pili Torti, Trichonodosis, Cartilage Hair Hypoplasia, and Other. Discussion of these diseases and disorders is deferred to Chapter 5 so that the reader may refer to Figure 5.21.1, which illustrates them.

3.23 Miscellaneous Characteristics

Miscellaneous characteristics are those characteristics that do not fit into any of the other categories listed in the various tables presented in this atlas. These characteristics are listed in Table 3.1. Miscellaneous characteristics include Double Medulla, Streaky Medulla, Gapping Pigment, Debris Present, Trailing Ovoid Bodies, and Other. Photographic archetypes illustrating examples of those miscellaneous characteristics are presented in Chapter 5. The variate Other may include any other notable characteristic not discussed here. Any unusual characteristics should be described fully in the notes and augmented with photographs in the examiner's or researcher's case file.

3.24 Insect, Arachnid, and Fungal Presence and Damage

The insect, arachnid, and fungal presence and damage listed in Table 3.1 includes lice/louse eggs, insect/arachnid damage, fungal damage, and other. The presence of louse eggs is easily diagnosed from the characteristic appearance of the egg attached to the hair shaft. Insect or arachnid damage can usually be diagnosed from the patterned appearance of the damage, while fungal damage has a more amorphous aspect. The variate Other refers to biological damage to hair that cannot be categorized easily as insect/arachnid or fungal damage. Photographic examples of each variate are presented in Chapter 5.

Human Hair Cross-Section Characteristic Variates

4

Table 4.1 lists the following microscopic characteristic variates as seen in cross-section mounts of the hair: cross-section shape, cuticle thickness, pigment density, pigment size, pigment distribution, and cortical texture. This chapter provides a brief description of each cross-section characteristic. Photographic archetypes that illustrate cross-section shape and cross-section pigment distribution are presented in Chapter 5. For a discussion on cross-section techniques, see Fong and Inami.[17]

It should be noted that the cross-section view of most characteristics does not represent additional "characteristics" for the purpose of hair comparison but rather adds a different view of the same characteristic. The cross-section may, however, resolve a question regarding the precise diagnosis of a characteristic that is difficult to diagnose in the longitudinal mount. The cross-section may assist in resolving questions regarding the pigment distribution about the medulla, the precise cross-section shape, or the cross-section cortical texture. Cuticle thickness, pigment density, and pigment size usually can be easily diagnosed in the longitudinal view by an experienced examiner.

4.1 Shaft Cross-Section Shape

The hair shaft cross-section shape usually can be diagnosed by an experienced hair examiner in a longitudinal mount. However, in some cases, the cross-section view allows the examiner to be more precise and accurate in the assessment of cross-section shape, since the cross-section gives a direct view of the shape. The cross-section shape variates are listed as Round, Oval, Triangular, Flat, Kidney, and Shouldered. The triangular shape is seen often

Table 4.1 Human Hair Cross-Section Characteristics[a]

0.1	Shape					
	BB01	Round	BB02	Oval	BB03	Triangular
	BB04	Flat	BB05	Kidney	BB06	Shouldered
02.	Cuticle Thickness					
	CC01	Thin	CC02	Thick	CC03	Varies
03.	Pigment Density					
	DD01	Light	DD02	Medium	DD03	Heavy
	DD04	Opaque				
04.	Pigment Granule Size					
	EE01	Fine	EE02	Coarse		
05.	Pigment Distribution					
	FF01	Uniform	FF02	Peripheral		
	FF03	Central	FF04	One-sided		
06.	Cortical Texture					
	GG01	Absent	GG02	Present	GG03	Obscured

[a] Table 4.1 adapted from Table 3, Ogle, R. R., Jr., Individualization of human hair: the role of the hair atlas, *Microscope*, 46(1), 20, 1998. With permission.

in beard hairs and rarely in scalp hairs. The cross-section shape of the transitional hairs between the scalp and the beard area have not been studied adequately. Straight hairs typically will have a round cross-section shape. As the degree of curl increases, the cross-section shape becomes increasingly flattened so that the curliest hairs will exhibit the flattest shape.[18] Photographic archetypes representing each cross-section shape are presented in Chapter 5.

4.2 Cross-Section Cuticle Thickness

The variates for cross-section cuticle thickness are Thin, Thick, and Varies. Those categories correspond to the same categories as seen in the longitudinal mount and do not require photographic archetypes.

4.3 Cross-Section Pigment Density

The variates for pigment density in cross-section are the same as those for the longitudinal mount and therefore do not require photographic archetypes.

4.4 Cross-Section Pigment Granule Size

The variates for pigment size in cross-section are the same as those for the longitudinal mount. Thus, this category of variates does not require photographic archetypes.

4.5 Cross-Section Pigment Distribution

The variates for pigment distribution in a cross-section view include Uniform, Peripheral, Central, and One-sided. These variates can be more easily diagnosed in the cross-section view than in the longitudinal mount. Photographic archetypes representing each cross-section pigment distribution are presented in Chapter 5.

4.6 Cross-Section Cortical Texture

The variates for the cross-section cortical texture are the same as those listed for the longitudinal view. The variates include Absent, Present, and Obscured. In the longitudinal view, the presence of cortical texture typically is demonstrated as a streaky appearance. In the cross-section view, however, the presence of cortical texture can be demonstrated as a granular appearance. Large bundles of fibers may account for the streaky texture in longitudinal mount and for the granular appearance of the cortex in cross-section. Research in the ultrastructure of the hair cortex may resolve the nature of the difference in texture as seen in longitudinal and cross-section views.

Human Hair Microscopic Characteristics: Photographs and Drawings of Variate Archetypes and Examples

5

Chapter 5 introduces photographs of both the microscopic characteristic variates that define the variate class limits for those characteristics having continuous variates (e.g., color) and photographic examples of the variates for those microscopic characteristics having discontinuous variates (e.g., pigment in cuticle). For those microscopic characteristics for which no photographs were available to the authors, line drawings of the characteristics are presented (e.g., hair diseases and disorders). The figures are presented in the same order as they appear in the tables and descriptions in Chapters 3 and 4 to facilitate use of the atlas by hair researchers and examiners for scoring of the characteristic variates seen in study hairs. The photographic figures represent the archetypes that define the variate class limits between adjoining variates. For hair examinations in which numerical scoring may not be applied, the photographic figures presented in this chapter can be used as a general guide when evaluating the microscopic characteristics of a subject hair.

5.1 Color

The color variates represented by the photographs are from Table 3.1 and include Colorless, Blond, Golden Brown, Brown, Gray Brown, Red, Red Brown, and Other. The designation Other is included to represent colors that may not be included in the color scheme presented in this atlas.

The photographic figures that represent the color variates are presented in two formats. Figure 5.1.0* demonstrates all of the color variates (representing color and shade) on a single page. That provides a hair color palette so that the user can more easily determine which color and shade is most similar to a subject hair. The photographic figures are then presented in larger format (fewer photographs per page) to allow the user to more easily visualize each color variate.

5.1.1 Colorless Hair

Figures 5.1.1 and 5.1.2 are examples of Colorless (White/Gray) hairs.

5.1.2 Blond Hair

The variates for Blond hair include Light Blond, Light to Medium Blond, Medium to Dark Blond, and Dark Blond. These variates are divided using three photographic archetypes. Figure 5.1.3 is the archetype for the variate class limit between Light Blond and Light to Medium Blond hairs. Figure 5.1.4 is the archetype for the variate class limit between Light to Medium and Medium to Dark Blond hairs. Figure 5.1.5 is the archetype for the variate class limit between Medium to Dark and Dark Blond hairs.

5.1.3 Golden Brown Hair

The variates for Golden Brown hair color are Light Golden Brown, Light to Medium Golden Brown, Medium to Dark Golden Brown, and Dark Golden Brown. These variates are divided using three photographic archetypes. Figure 5.1.6 is the archetype for the variate class limit between Light Golden Brown and Light to Medium Golden Brown hairs. Figure 5.1.7 is the archetype for the variate class limit between Light to Medium and Medium to Dark Golden Brown hairs. Figure 5.1.8 is the archetype for the variate class limit between Medium to Dark and Dark Golden Brown hairs.

5.1.4 Brown Hair

The variates for Brown hair are Light Brown, Light to Medium Brown, Medium to Dark Brown, Dark Brown to Opaque, and Opaque. These variates are divided using three photographic archetypes; a fourth archetype represents an Opaque hair. Figure 5.1.9 is the archetype for the variate class limit between Light Brown and Light to Medium Brown hairs. Figure 5.1.10 is the archetype for the variate class limit between Light to Medium Brown and Medium to Dark Brown hairs. Figure 5.1.11 is the archetype for the variate

* All color figures appear after page 48.

class limit between Medium to Dark Brown and Dark Brown to Opaque hairs. Figure 5.1.12 is an example of an Opaque hair.

5.1.5 Gray Brown Hair

The variates for Gray Brown hair are Light Gray Brown, Light to Medium Gray Brown, Medium to Dark Gray Brown (Black), and Dark Gray Brown (Black) to Opaque. These variates are divided using three photographic archetypes. Figure 5.1.13 is the archetype for the variate class limit between Light Gray Brown and Light to Medium Gray Brown hairs. Figure 5.1.14 is the archetype for the variate class limit between Light to Medium and Medium to Dark Gray Brown (Black) hairs. Figure 5.1.15 is the archetype for the variate class limit between Medium to Dark Gray Brown (Black) and Dark Gray Brown hairs (Black) to Opaque hairs. For an example of an Opaque hair, see Figure 5.2.4.

5.1.6 Red Hair

The variates for Red hair color are Light Red, Light to Medium Red, Medium to Dark Red, and Dark Red. These variates are divided using three photographic archetypes. Figure 5.1.16 is the archetype for the variate class limit between Light Red and Light to Medium Red hairs. Figure 5.1.17 is the archetype for the variate class limit between Light to Medium and Medium to Dark Red hairs. Figure 5.1.18 is the archetype for the variate class limit between Medium to Dark and Dark Red hairs.

5.1.7 Red Brown Hair

The variates for Red Brown hair are Light Red Brown, Light to Medium Red Brown, Medium to Dark Red Brown, and Dark Red Brown. These variates are divided using three photographic archetypes. Figure 5.1.19 is the archetype for the variate class limit between Light Red Brown and Light to Medium Red Brown hairs. Figure 5.1.20 is the archetype for the variate class limit between Light to Medium and Medium to Dark Red Brown hairs. Figure 5.1.21 is the archetype for the variate class limit between Medium to Dark Red Brown and Dark Red Brown hairs.

5.1.8 Other Color Hair

The variate Other can include a large number of artificial hair colors that can range from jet black to the colors of the rainbow. Figures 5.1.22 and 5.1.23 are examples of artificially colored hairs that are not included in the color scheme presented in this atlas.

5.2 Pigment Density

Pigment density refers to the abundance of the pigment granules in the hair shaft cortex as seen in longitudinal mount. The variates for pigment density are Absent, Light, Light to Medium, Medium to Heavy, Heavy to Opaque, and Opaque. These variates are divided using three photographic archetypes, with a fourth archetype representing an Opaque hair. Refer to Figures 5.1.1 and 5.1.2 for examples of the variate Absent, which refers to the absence of pigment granules in the hair shaft cortex. Figure 5.2.1 is the archetype for the variate class limit between Light and Light to Medium pigment density. Figure 5.2.2 is the archetype for the variate class limit between Light to Medium and Medium to Heavy pigment density. Figure 5.2.3 is the archetype for the variate class limit between Medium to Heavy and Heavy to Opaque pigment density. Figure 5.2.4 is an example of a hair with Opaque pigment density.

5.3 Pigment Granule Size

Pigment granule size refers to the relative size of the pigment granules as defined by the variate archetypes for this characteristic. The variates include Absent/Obscured, Fine, and Coarse. Refer to Figure 5.1.1 and 5.1.2 for examples of the variate Absent and Figure 5.2.4 for an example of the variate Obscured. Figure 5.3.1 illustrates an example of Fine pigment granule size. Figure 5.3.2 is an example of a hair with Coarse pigment granule size. Study hairs should be scored according to which example is closest to the study hair. When it is unclear as to which example is closest to the study hair, it should be scored as the higher category (Coarse) in accordance with the convention for scoring ambiguous hairs.

5.4 Pigment Distribution

Pigment distribution refers to the distribution of the pigment granules as seen in longitudinal mount. The variates for pigment distribution include Absent, Uniform, Peripheral, One-sided, Central, Random, and Other. Figures are presented that represent each pigment distribution. Absent refers to the absence of pigment in colorless hair (see Figure 5.1.1). Figure 5.4.1 is an example of a hair with Uniform pigment distribution. Figure 5.4.2 is an example of a hair with Peripheral pigment distribution. Figure 5.4.3 is an example of a hair with One-sided pigment distribution. Figure 5.4.4 is an example of a hair with Central pigment distribution. Figures 5.4.5 and 5.4.6 are examples of hairs with Random pigment distribution.

5.5 Pigment Aggregate Shape

Pigment aggregate shape refers to the shape of the pigment aggregates in those hairs having aggregated pigment. The variates for aggregation include Absent/No Aggregates, Streaked, Clumped, and Other. Figures are presented that represent each aggregate shape. The variate Absent/No Aggregates refers to those hairs in which there is either no pigment or no apparent aggregation of the pigment granules. The variate Other refers to either a mixture of Streaked and Clumped aggregates or a form of aggregation that may not be represented by the terms Streaked or Clumped. Figure 5.5.1 is an example of the variate No Aggregates. Figure 5.5.2 is an example of a hair with a Streaked pigment aggregate shape. Figure 5.5.3 is an example of a hair with a Clumped pigment aggregate shape. Figure 5.5.4 is an example of a hair with a mix of streaks and clumps. It is categorized as belonging to the variate Other.

5.6 Pigment Aggregate Size

Pigment aggregate size refers to the relative size of the pigment aggregates as seen in longitudinal mount. The variates for pigment aggregate size are Absent/No Aggregates, Small Streaks, Medium Streaks, Large Streaks, Small Clumps, Medium Clumps, Large Clumps, and Other. These variates are divided using four photographic archetypes. The variate Absent/No Aggregates refers to either those hairs with no pigment or those hairs that have no apparent aggregation of the pigment granules (see Figure 5.5.1). Figure 5.6.1 is an example of a hair that contains Small Streaks. Figure 5.6.2 serves as the archetype for the variate class limit between Small Streaks and Medium Streaks. Figure 5.6.3 serves as the archetype for the variate class limit between Medium Streaks and Large Streaks. Figure 5.6.4 is an example of hair with Small Clumps. Figure 5.6.5 serves as the archetype for the variate class limit between Small Clumps and Medium Clumps. Figure 5.6.6 serves as the archetype for the variate class limit between Medium Clumps and Large Clumps.

5.7 Medulla Continuity

Medulla continuity refers to the appearance of the opaque and translucent forms of the medulla in longitudinal mount and includes the variates Absent/Obscured, Continuous, Interrupted, and Fragmentary. Figures 5.7.1 and 5.7.2 are examples of an Absent medulla (the variate Absent/Obscured). Figure 5.7.3 is an example of an Obscured medulla (the variate

Absent/Obscured). Figures 5.7.4 and 5.7.5 are examples of the variate Continuous. Figure 5.7.6 is an example of the variate Interrupted. Figure 5.7.7 is an example of the variate Fragmentary. The variates for medulla continuity also include combinations of the three variates Continuous, Interrupted, and Fragmentary: Continuous/Interrupted, Continuous/Fragmentary, Interrupted/Fragmentary, and Continuous/Interrupted/Fragmentary. These combinations are not shown in the photographic figures, since the determination of their existence requires the examiner to search along the hair shaft and they cannot be depicted in a single photograph.

5.8 Medulla Opacity

Medulla opacity refers to the appearance of the medulla as seen in longitudinal mount. The variates for medulla opacity include Absent/Obscured, Opaque, Translucent, and Opaque/Translucent. The term Absent/Obscured represents those hairs that lack a visible medulla or those hairs with medullas obscured by heavy pigmentation. Refer to Figures 5.7.1, 5.7.2, and 5.7.3 for examples of variate Absent/Obscured. Figure 5.8.1 depicts a hair with an Opaque medulla. Figure 5.8.2 represents a hair with a Translucent medulla. Figure 5.8.3 depicts a hair with an Opaque/Translucent medulla.

5.9 Cuticle Thickness

The variates for cuticle thickness are Thin, Thick, Varies, and Not Apparent. The variates Thin and Thick are based on measurement. Figures 5.9.1 and 5.9.2 are examples of the variate Thin cuticle. Figures 5.9.3 and 5.9.4 are examples of the variate Thick cuticle. Figure 5.9.5 is an example of a cuticle with variable thickness (Varies). Refer to Figure 5.10.1 for an example of a cuticle thickness Not Apparent due to an indistinct cuticle margin.

5.10 Inner Cuticle Margin

The inner cuticle margin is the border between the cuticle and the cortex. The variates for inner cuticle margin are Indistinct, Distinct, and Varies. Figure 5.10.1 illustrates a hair with an Indistinct inner cuticle margin. Figure 5.10.2 illustrates a hair with a Distinct inner cuticle margin. Figure 5.10.3 illustrates a hair with an inner cuticle margin described by the term Varies.

5.11 Outer Cuticle Scale Profile

The term outer cuticle scale profile refers to the appearance of the outer edge of the cuticle when viewed in longitudinal mount. The variates for outer cuticle scale profile are Smooth, Serrated, Ragged, Looped, and Other. Figure 5.11.1 is an example of a hair with a Smooth outer cuticle scale profile. Figure 5.11.2 is an example of a hair with a Serrated outer cuticle scale profile. Figure 5.11.3 illustrates a hair with a Ragged outer cuticle scale profile. Figure 5.11.4 depicts a hair with a Looped outer cuticle scale profile.

5.12 Cuticle Surface

The cuticle surface is viewed as a longitudinal air mount or as a cast of the cuticle surface. The variates for the cuticle surface are Normal and Damaged. Figure 5.12.1 illustrates a Normal cuticle surface. Figure 5.12.2 illustrates a Damaged cuticle surface.

5.13 Pigment in Cuticle

The variates for pigment in the cuticle are Absent (no pigment in the cuticle) and Present (pigment is present in the cuticle). Figure 5.13.1 is an example of the variate Absent. Figure 5.13.2 is an example of the variate Present.

5.14 Cortical Texture

The variates for cortical texture are Absent, Present, and Obscured. The term Present normally refers to a Streaky texture, but other observed textures may also be scored Present. Figure 5.14.1 illustrates a hair with no cortical texture (variate Absent). Figures 5.14.2 and 5.14.3 illustrate hairs with cortical texture (variate Present). Figure 5.14.4 illustrates a hair with the cortical texture obscured by heavy pigmentation (variate Obscured).

5.15 Cortical Fusi

The variates for cortical fusi are Absent, Root Only, Rare, Common, Profuse, and Obscured. Figure 5.15.1 illustrates a hair with no cortical fusi present (variate Absent). There are no figures to illustrate the variates Root Only and

Obscured. The remaining variates are divided using two photographic archetypes. Figure 5.15.2 serves as the archetype for the variate class limit between Rare cortical fusi and Common cortical fusi. Figure 5.15.3 serves as the archetype for the variate class limit between Common cortical fusi and Profuse cortical fusi.

5.16 Ovoid Bodies

The variates for ovoid bodies include Absent, Few, Many, and Obscured. There are no figures to illustrate the variates Absent and Obscured. The variates Few and Many are determined by number. Figures 5.16.1 and 5.16.2 are examples of hair segments with Few ovoid bodies. Figures 5.16.3 and 5.16.4 are examples of hair segments with Many ovoid bodies. The user of this atlas should keep in mind that each photograph represents only a portion of a hair and that the quantitative scoring of ovoid bodies is determined by the examination of the entire length of the hair.

5.17 Root Growth Stage

The variates for root growth stage are Absent, Anagen, Catagen, and Telogen. There are no figures to illustrate the variates Absent and Catagen. The Catagen root growth stage is a transitional stage, and it is difficult to demonstrate the stage with a single photograph. Figure 5.17.1 depicts an Anagen growth stage hair root. Figure 5.17.2 depicts a Telogen growth stage hair root.

5.18 Distal Tip Characteristics

The variates for distal tip characteristics are Natural Taper, Rounded Taper, Square Cut/Straight Edge, Angled Cut/Straight Edge, Square Cut/Rounded Edge, Angled Cut/Rounded Edge, Split, Frayed, Crushed, Singed, Broken, and Other. Figure 5.18.1 depicts a Natural Taper distal hair tip. Figure 5.18.2 depicts a Rounded Taper distal hair tip. Figure 5.18.3 illustrates a Square Cut/Straight Edge distal hair tip. Figure 5.18.4 portrays an Angled Cut/Straight Edge distal tip. Figure 5.18.5 illustrates a Square Cut/Rounded Edge distal tip. There is no figure for Angled Cut/Rounded Edge. Figure 5.18.6 illustrates a Split distal tip. Figure 5.18.7 depicts a Frayed distal tip. Figure 5.18.8 portrays a Crushed distal tip. Figure 5.18.9 illustrates a Singed distal tip. Figure 5.18.10 depicts a Broken distal tip.

5.19 Shaft Aberration

The variates for shaft aberration include Normal, Buckling, Shouldering, Splitting, Undulating, and Convoluting. Figure 5.19.1 portrays Buckling of the hair shaft. Figure 5.19.2 illustrates Splitting of the hair shaft. Figure 5.19.3 depicts Undulating of a hair shaft. Figure 5.19.4 portrays Convoluting of a hair shaft. There are no longitudinal photographic illustrations for the variates Normal and Shouldering. See Figures 5.24.6 and 5.24.7 for cross-sectional photographic examples of the variate Shouldering.

5.20 Hair Treatments

The variates for hair treatments include Absent/Not Apparent, Dyed, Bleached, Permed, Combination, and Other. The term Other is given to provide for any hair treatment encountered that is not addressed by those listed. Figure 5.20.1 is an example of Dyed hair with a stained cuticle. Figures 5.20.2 and 5.20.3 are examples of Dyed hair with a demarcation line between the dyed and undyed portions of the hair. Figure 5.20.4 is an example of an Artificially Bleached hair. Figure 5.20.5 is an example of an Artificially Bleached hair demonstrating cortex damage as a result of the bleaching process. Figure 5.20.6 is an example of curler damage on a Permed hair.

5.21 Hair Diseases and Disorders

The hair diseases and disorders listed in Chapter 3 are Trichorrhexis Nodosa, Trichorrhexis Invaginata, Trichoschisis, Pili Annulati, Monilethrix, Pili Torti, Trichonodosis, Cartilage Hair Hypoplasia, and Other. The term Other is provided to allow the examiner to score a hair disease or disorder not listed specifically in Chapter 3. Each of the hair diseases and disorders listed here is illustrated in Figure 5.21.1.

5.21.1 Trichorrhexis Nodosa (see Figure 5.21.1)

Trichorrhexis Nodosa appears along the hair shaft as small, beaded swellings associated with a loss of cuticle. The expanded areas are composed of frayed cortical fibers through which the hair readily fractures.[19]

5.21.2 Trichorrhexis Invaginata (see Figure 5.21.1)

Trichorrhexis invaginata is a condition in which the hair shaft folds back into itself, forming a "ball and socket" pattern in the shaft.[20]

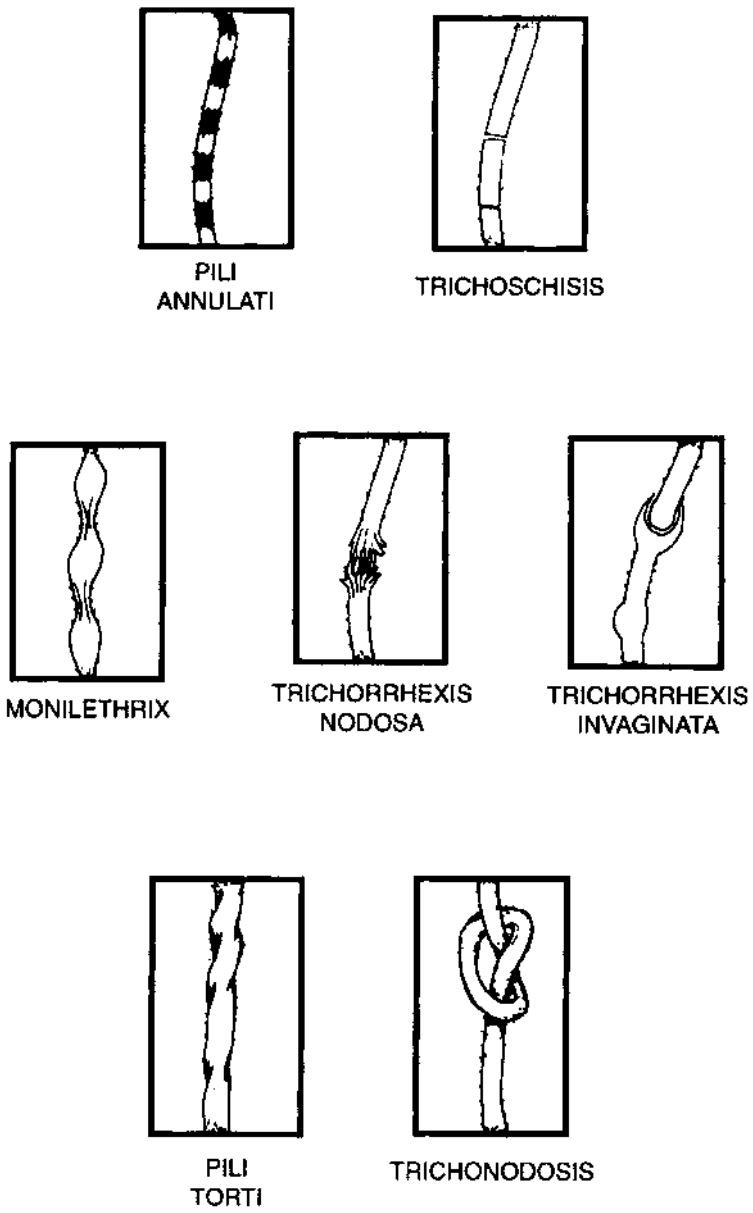

Figure 5.21.1 Drawings of hair diseases and disorders. (Adapted from Figures 8, 13, and 18, Whiting, D. A., Structural abnormalities of the hair shaft, *J. Am. Acad. Dermatol.*, 16(1), 1987, with permission.)

5.21.3 Trichoschisis (see Figure 5.21.1)

Trichoschisis is a clean, transverse fracture across the hair shaft through cuticle and cortex and is associated with a localized absence of cuticle cells.[21]

5.21.4 Pili Annulati (see Figure 5.21.1)

Pili Annulati, also called ringed hair, has characteristic alternating light and dark bands in the hair shaft when viewed with transmitted light. The colors of the bands are reversed when viewed with reflected light.[22]

5.21.5 Monilethrix (see Figure 5.21.1)

Monilethrix is a condition in which the hair shaft has characteristic elliptic nodes, 0.7 to 1 mm apart, with intervening tapered constrictions that are nonmedullated.[23] The hair shaft is not twisted between the evenly spaced nodes.

5.21.6 Pili Torti (see Figure 5.21.1)

In Pili Torti, the hair shaft is flattened and twisted through 180 degrees on its axis. Typically, four or five twists are found at irregular intervals along the hair shaft, giving it a beaded appearance.[24]

5.21.7 Trichonodosis (see Figure 5.21.1)

Trichonodosis consists of knotting of the hair shaft. The condition is uncommon and is found mostly in the short, curly hair of African heritage individuals or in European heritage individuals with short, curly hair.[25]

5.21.8 Cartilage Hair Hypoplasia

Cartilage Hair Hypoplasia is a condition of the hair found in certain forms of dwarfism. The hairs are fine, light colored, and sparse but do not differ from normal hair with the exception that their diameter is reduced.[26] This condition is not illustrated.

5.22 Miscellaneous Characteristics

Those miscellaneous characteristics listed in Chapter 3 are Double Medulla, Streaky Medulla, Gapping Pigment, Debris Present, Trailing Ovoid Bodies, and Other. The term Other is added to the list to allow the examiner to score

a miscellaneous characteristic not specifically listed here. Figures 5.22.1 and 5.22.2 depict head hairs with Double Medullas. Figure 5.22.3 illustrates a beard hair with a Streaky Medulla. Figure 5.22.4 portrays a hair with Gapping Pigment. Figure 5.22.5 illustrates a hair with Trailing Ovoid Bodies. Figures 5.22.6, 5.22.7, and 5.22.8 depict some of the variations seen in beard hair. Figure 5.22.9 illustrates a head hair with a Streaky Medulla. There is no figure that represents a hair with Debris.

5.23 Insect, Arachnid, and Fungal Presence and Damage

Figure 5.23.1 illustrates a hair shaft with a louse egg attached. Figure 5.23.2 depicts a hair shaft with insect/arachnid damage. Figure 5.23.3 depicts a hair shaft with fungal damage. Figure 5.23.4 depicts a putrid hair root (a root exposed to bacterial degradation) from a decomposing skull.

5.24 Cross-Sectional Shape

The variates for cross-sectional shape include Round, Oval, Triangular, Flat, Kidney, and Shouldered. Photographic archetypes are presented that represent each cross-sectional shape. Figure 5.24.1 illustrates a Round cross-sectional shape. Figure 5.24.2 illustrates an Oval cross-sectional shape. Figure 5.24.3 illustrates a Triangular cross-sectional shape. Figure 5.24.4 illustrates a Flat cross-sectional shape. There is no figure for a Kidney cross-sectional shape. Figures 5.24.5 and 5.24.6 illustrate Shouldered cross-sectional shapes.

5.25 Cross-Sectional Pigment Distribution

The variates for cross-sectional pigment distribution include Uniform, Peripheral, Central, and One-sided. Photographic archetypes are presented that illustrate each cross-sectional pigment distribution. Figure 5.25.1 illustrates a hair with Uniform cross-sectional pigment distribution. Figure 5.25.2 illustrates a hair with Peripheral cross-sectional pigment distribution. Figure 5.25.3 illustrates a hair with Central cross-sectional pigment distribution. Figure 5.25.4 illustrates a hair with One-sided cross-sectional pigment distribution.

Human Hair Types

6

6.1 The Human Hair Type

A human hair type, as defined in Chapter 1, is the specific combination of certain genetically controlled macroscopic and microscopic characteristic variates observed in that hair. The macroscopic and microscopic characteristics that constitute the hair type are listed in Table 6.1. Characteristics A and B are from Table 2.1. The remaining characteristics are taken from Table 3.1. These are the characteristics that are the phenotypic expression of the individual's genotypes for hair production. Some of the characteristics included in Table 6.1 can be altered as a result of hair treatment or environmental exposure. Before the hair type of a subject hair is determined, characteristics such as color, degree of curl, outer cuticle profile, and pigment density should be evaluated to determine whether those characteristics are in their natural state. Characteristics that are not genetically related and known to be associated with hair treatments or environmental exposure (e.g., damage to cuticle) are not listed as components of hair type. The characteristics that define hair type are listed in Table 6.1, with an alphabetic prefix for each characteristic so that when the characteristic variate scores that identify the hair type are depicted as an ordered series, each of the variates is preceded by its alphabetic identifier. These alphabetic identifiers are also indicated in Table 2.1 and Table 3.1 for the users' reference. The alphabetic prefix facilitates checking to make sure that each of the characteristics is represented in the ordered series of variates for each hair scored.

As an illustration of the use of Table 2.1, Table 3.1, and Table 6.1 for the purpose of scoring, the hair type of a subject hair is listed below. A hair that is (A) wavy (02), with a (B) degree of curl of a circle with a diameter between 5 and 10 cm (04), is (D) Medium to Dark Brown (23), has (E) pigment

Table 6.1 Hair Type Characteristic Varieties[a]

A.	Hair Form	B.	Degree of Curl
D.	Color	E.	Pigment Density
F.	Pigment Granule Size	G.	Pigment Distribution
H	Pigment Aggregate Shape	I.	Pigment Aggregate Size
J.	Medulla Continuity	K.	Medulla Opacity
L.	Cuticle Thickness	M.	Inner Cuticle Margin
N.	Outer Cuticle Profile	P.	Pigment in Cuticle
Q.	Cortical Texture	R.	Cortical Fusi
S.	Ovoid Bodies	V.	Maximum Shaft Diameter

Note: The characteristics and the alpha prefixes listed in the table were taken from Table 2.1 and Table 3.1. Those letters that are not included in this list are alpha prefixes which have been assigned to other characteristics.

[a] Table 6.1 adapted from Table 3, Ogle, R. R., Jr., Individualization of human hair: the role of the hair atlas, *Microscope*, 46(1), 19, 1998. With permission.

density of Light to Medium (02), has (F) Coarse pigment granule size (02), has (G) Uniform pigment distribution (01), has (H) Absent pigment aggregation (00), has (I) Absent pigment aggregate size (00), has (J) a Continuous medulla (01), has (K) an Opaque medulla (01), has (L) a Thin cuticle (01), has (M) an Indistinct inner cuticle margin (01), a (N) Smooth outer cuticle scale profile (01), has (P) No pigment in the cuticle (01), is (Q) Absent of cortical texture (00), has (R) Rare cortical fusi (02), is (S) Absent of ovoid bodies, (00) and a (V) Medium maximum shaft diameter (02) would have the following alphanumerical array for describing its hair type:

A02-B04-D23-E02-F02-G01-H00-I00-J01-
K01-L01-M01-N01-P01-Q00-R02-S00-V02

The use of this scoring system may be extended to document not only those genetically controlled characteristics that define hair type but also the combination of all the characteristics presented in this atlas. Using the scoring system to document all characteristics may be useful to the hair examiner when performing a forensic hair comparison.

6.2 Regional Human Hair Characteristic Variates

The older terms "Mongoloid," "Caucasoid," and "Negroid" used to describe the major population groups of humankind are replaced in this atlas with the more modern terms East Asian, European, and African (meaning sub-Saharan African), respectively. These terms were adapted from Brace.[27] The populations of the Indian subcontinent are allied with the European populations in terms

of anthropological kinship.[28] However, the scalp hair of the Indian subcontinent populations is more closely allied with the hair type of the East Asian populations, as is the scalp hair of the native populations of North, Central, and South America. Although the native populations of the Americas are allied with the East Asians anthropologically, many of the populations of Mexico and the other countries of Central and South America are of mixed heritage, so the scalp hair of these populations may represent characteristics consistent with those of a mixed heritage.

Forensic anthropologists rely primarily on skeletal analysis for an accurate estimate of original geographic origins. The depth of skin pigmentation has considerable overlap between individuals of African, European, and East Asian geographical origin, as does hair form among individuals of European, African and East Asian populations. Hair color, form, and degree of curl, however, can provide an indication of the geographical ancestry of the individual from whom a questioned hair originated. Those indications of the geographical heritage of an individual who is the source of a questioned hair can be of considerable value in the forensic examination of human hair, particularly with regard to providing investigative leads as to the possible regional ancestry of the individual from whom a questioned hair originated.

6.2.1 Regional Shaft Diameter

The diameter for African ancestry hair is smaller than that for the other two groups,[29] but note that these highly curled hairs will lie on their side oriented with the smaller diameter of the flattened cross-section of the hair facing upward. That orientation will necessarily show the smaller of the two diameters in the view of the longitudinal mount. The regional hair shaft diameter for East Asian ancestry individuals is thicker than those of the other two regional groups. The hair shaft diameter for European region heritage individuals is intermediate between the African heritage and East Asian heritage groups, but it has considerable overlap with both of these groups.[30] Further studies involving the consistent measurement of the maximum shaft diameter (the maximum cross-sectional shape) of hairs with known ancestry may be valuable in better establishing the relationship between maximum shaft diameter and regional ancestry.

6.2.2 Regional Cross-Sectional Shape

The cross-sectional shape for the African heritage hair is flattened or ribbon shape, nearly round in the East Asian heritage hair, and varies widely in European heritage hair, from the flattened shape seen in the African hair to the near round shape of the East Asian hair.

6.2.3 Regional Pigmentation

The pigmentation pattern for African heritage hair is dense and clumped, whereas the pattern for East Asian heritage hair is dense but normally does not show the clumping seen in African heritage hair.[31] European heritage hair ranges from very light density to very heavy density, and it overlaps considerably the other two groups. The pigment aggregation in European hairs is usually limited to streaky aggregates without the clumping seen in the African hair type.

6.2.4 Regional Cuticle Thickness

African heritage hair normally has a thin cuticle, while Asian hair usually has a thick, prominent cuticle. European hair varies widely and overlaps completely the cuticle thickness of the African heritage and the East Asian heritage hair forms. The cuticle of the European heritage hair can vary from an invisible cuticle to the thickness seen in East Asian heritage hairs.

6.2.5 Hair Form

Hair form is diagnostic for African heritage hair,[32] since the high degree of curl seen in the African heritage hair is rare in European heritage hair and largely unknown in East Asian heritage populations. But it is also present in some other populations, e.g. Papua New Guinea native populations. The hair form for East Asian heritage populations is uniformly straight, but note that many populations allied with the East Asian heritage groups may have hair that can be quite curly. The European heritage hair form varies widely, from a curl near that of the African heritage groups to the straight hair seen in the East Asian heritage groups. Further research is needed from the forensic community to characterize the hair forms of the many populations throughout the Pacific islands and other world populations so that the hair form of those populations may be added to future editions of this or other atlases.

6.3 Regional Pubic Hair Characteristics

The pubic hair form is also related to the regional origin heritage of the individual. Individuals with East Asian heritage have pubic hair that is typically black and wavy. Individuals with African heritage have highly curled pubic hair, with a form near that of the scalp hair. The pubic hair of African heritage individuals is typically black in color but may have other colors owing to admixture with individuals of European descent. Individuals with European heritage have pubic hair with a wide variation in form that may be curly and convoluted but lacks the wavy form seen in East Asian pubic

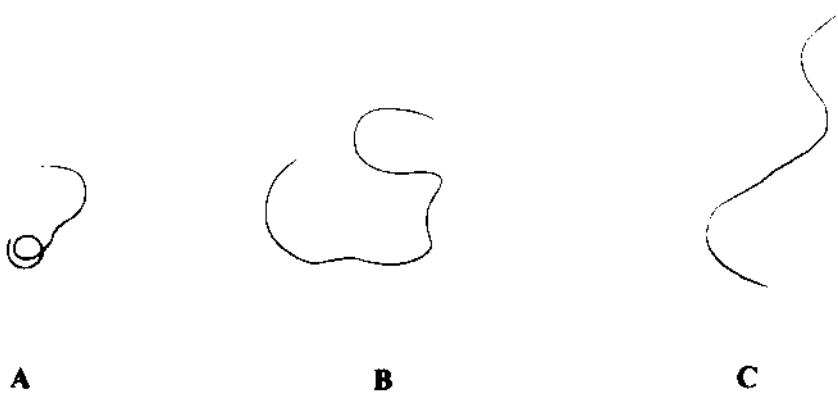

Figure 6.1 Pubic hairs from (A) individual of African heritage, (B) individual of European heritage, and (C) individual of East Asian heritage.

hair or the high degree of curl seen in the African pubic hair. The color of European heritage individuals' pubic hair ranges widely and is correlated with the scalp hair color. Figure 6.1 illustrates the typical hair form for African heritage pubic hair (A), the typical hair form for European pubic hair (B), and the typical hair form for East Asian pubic hair (C).

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Glossary

Aberration (Shaft) An abnormal or unusual condition of the hair shaft due to a genetic disorder, disease or environmental damage.

Aggregation (Pigment) The appearance of the pigment granules when they are concentrated in a mass that has a recognizable form.

Amorphous Literally, "without form"; a form that does not fit into a category of a defined form pattern.

Anagen The active growth phase of a hair root in the hair growth cycle. The root of an anagen hair is elongated, is covered with a root sheath, and is fully pigmented.

Archetype A model against which other similar objects can be compared to establish degrees of similarity or dissimilarity.

Artifacts Features that are the result of damage, optical distortion, or other factors; not a true feature.

Attribute Synonym for characteristic.

Buckling A disruption of the hair shaft demonstrating itself as an abrupt change in direction with or without a slight twist. This feature may be due to genetic factors, or it may result from damage (i.e., hair treatments).

Catagen The transitional phase of the hair root from the active growth phase (anagen) to the resting growth phase (telogen) in the hair growth cycle. The root of a catagen hair may have a club-shaped root, a sparse amount of pigment, and a dried up root sheath.

Categorize Identify the variate class to which a hair characteristic belongs; scoring of a study hair through use of the archetypes in this atlas.

Characteristic A microscopic or macroscopic feature, attribute, or trait of a hair.

Characterize The process of examining and describing the characteristics of a hair or a set of hairs.

Class A category of hair (e.g., scalp hair, dog hair) or a group of hairs defined by the presence in each hair of all the class characteristics that define the class, e.g., an East Asian heritage hair type.

Class Characteristic A characteristic shared by all members of a class. It may vary in some way from one member to the next (e.g., size, shape, color, position) but is present in each member of the class. When variation is present, the characteristic may be used as part of ***a set of other class characteristics*** also exhibiting some variation to establish ***a set of characteristics*** of which ***the aggregate constitutes a unique set of characteristic variates*** that may allow for individualization of the object bearing those characteristics.

Club Hair A hair which has a root that is surrounded by a bulbous enlargement composed of completely keratinized cells, preliminary to normal loss of the hair from the follicle; Telogen hair.

Color The hue of the hair as judged either macroscopically or microscopically.

Comparative Analysis The most common type of analysis in forensic examinations in which a questioned object (questioned source) is compared to a known (an object of known source) for the purpose of determining if the questioned and known objects have the same source, as opposed to the comparison to an archetype in which the purpose is to classify the hair characteristic variate under consideration (determine the variate class to which the hair characteristic variate belongs).

Continuous Variation Variation where the difference between one characteristic variate and its closest neighbor in terms of similarity is virtually indiscernible. Example: A particular shade of brown hair is indistinguishable from the shade of a brown hair slightly darker or lighter, since the number of shades of brown hair is very large and the eye's ability to distinguish shades is limited.

Convoluting Rotation or twisting of the hair shaft, which can occur naturally or as a result of mechanical force. The hair shaft of a convoluted hair may loop or twine upon itself.

Cortex The major portion of the hair shaft, between the cuticle and the medulla, composed of elongated and fusiform cells.

Cortical Fusi Small, fusiform bodies within the hair shaft cortex that have the appearance of empty membranes; they may be filled with air or liquid.

Crenate Having a rounded or scalloped margin, as is said of the distal edge of hair scales.

Cross-section A thin section of the hair shaft cut at right angles to the longitudinal axis.

Curl The degree of curvature of a hair along its long axis; curliness.

Cuticle The covering of the hair shaft, composed of overlapping scales.

Density (Pigment) The relative abundance of pigment granules in the hair cortex, as judged by their microscopic appearance.

Discontinuous Variation Each variate of a characteristic has a recognizable form that is different from the other variates; i.e., each variate differs ***qualitatively*** from the others (cf. ***Continuous Variation***).

Distribution (Pigment) The distribution pattern of the pigment granules about the central axis of the hair shaft (Uniform, Peripheral, One-sided, Random, or Central).

Exemplar Synonym for known (an item of known source) or a representative sample taken from the known for comparison to a Questioned item.

Feature Synonym for characteristic.

Fusi The spindle-shaped air or fluid-filled bodies found in some hair shafts or their flattened bodies, which have lost the air or fluid with which they were filled (also called cortical fusi).

Fusiform Tapering at each end; spindle-shaped.

Hair Form The spacial configuration of a hair with respect to curliness.

Hair Type The specific combination of genetically controlled macroscopic and microscopic characteristic variates observed in a particular hair.

Identification The process of identifying the class to which an object belongs; in some forensic disciplines, it is used in the same sense as individualization (e.g., fingerprints, firearms).

Imbricate Having the edges overlapping in a regular pattern.

Individualization The identification of the unique source of an object. With respect to a questioned hair, identification of the individual from whom the hair originated. The individualization of human hair is rarely achievable using microscopy techniques.

Keratin Any of various sulphur-containing fibrous proteins that form the chemical basis for keratinized epidermal tissues such as hair, nails, feathers, and horns of animals.

Known Term used to designate an item or object with a known source; used as a comparison standard.

Lice (Plural of louse) Parasitic insects. Those found on man include head lice (*Pediculus humanus capitis*), body or clothing lice (*Pediculus humanus corporis*), and crab lice (*Phthirus pubis*), which live in the pubic region, eyelashes, or eyebrows. The eggs of the lice may be seen attached to the hair shaft.

Limited Range A term coined by hair examiners to designate the smaller range of a variate seen in the hair from an individual as opposed to the wider range of the variate in the human population.

Longitudinal Plane Parallel to the long axis of the hair.

Looped A condition in which the distal edges of the cuticle scales are curved inward so that they curve or cup toward the edge of the hair shaft. Looped scales can trap air below the curved portion, giving the appearance of dark bands between the scale and the shaft.

Macroscopic Large enough to be perceived without magnification.

Magnification Levels (As applied to human hair examinations) Macroscopic — Observed with the unaided eye (also referred to as "gross"); stereoscopic (low-power) — Observed with the stereoscopic microscope (usually 3¥ to 70¥ magnification), but may be slightly higher or lower; high power — Compound microscope that may be 20¥ to 1000¥ magnification; scanning electron microscope — From compound light microscope magnification up to 250,000¥ magnification.

Medulla The central canal of cells of the hair shaft, which may appear black (air-filled cells) or translucent (fluid-filled cells). Pronounced either "mah-doo'-lah" or "meh-dull'-ah" as a personal preference.

Medulla Continuity The continuous or discontinuous nature of the opaque or translucent medulla from the proximal end to the distal end of the hair shaft.

Medulla Opacity The appearance of the medulla as being either opaque or translucent when viewed with transmitted light in the compound light microscope.

Melanin Brown pigments occurring in plants and animals; the pigment in human hair that provides the brown to black color of the hair.

Microscopic Too small to be perceived by the unaided eye but large enough to be studied under a microscope; examination under the microscope (same as microscopical).

Monilethrix A hair disorder that results in periodic nodes along the length of the hair with intervening, tapering constrictions that are not medullated.

Ovoid Bodies Oval-shaped pigmented bodies in the hair cortex.

Papilla A small projection at the base of the hair follicle composed of connective tissue.

Parfocal A microscope objective system designed to have similar focal distances so that when the objective turret is rotated to another objective, the object in view remains in focus.

Pili Annulati A hair disorder that results in ringed or banded hair; alternating bright and dark bands in the hair shaft.

Pili Torti A hair disorder demonstrated by a hair that is flattened and twisted through 180 degrees on its axis. It is found at irregular intervals along the shaft.

Planes Longitudinal — Plane parallel to the long axis of the hair; Transverse — Plane parallel to the short axis of the hair.

Questioned In forensic science, an item or object that has a questioned or unknown source.

Range Limits The upper and lower limits that describe the variation of a hair characteristic within a single hair, within the hairs of an individual's scalp, within the hairs of an unknown specimen, or within a given population of individuals.

Reference Standard A hair standard in a reference collection to be used as a comparison standard in hair research.

Regions of the hair:

Proximal — Area nearest the hair root.

Distal — Area farthest from the hair root.

Medial — Area between the proximal and distal areas of the hair shaft.

Note: These terms refer to the areas of a hair shaft as it exists, since cutting the hair results in a shift of the distal area.

Scales The keratinized scale-like covering of the hair; cuticle.

Serrate Having the appearance of the teeth of a saw; jagged.

Shade Degree of darkness of a color.

Spectrum The range of values exhibited collectively by all the individuals in a population with regard to a specific characteristic; the range of the variates of a hair characteristic in a population.

Telogen The end phase of the hair growth cycle during which the hair root becomes a club root and the hair eventually falls out of the follicle. The root of a telogen hair is club-shaped, with little or no adhering root sheath, and lacks pigment.

Translucent Transmitting light but causing sufficient diffusion to allow the perception of an image, as is said of the appearance of a medulla that has cells that are fluid-filled rather than air-filled.

Transverse Plane Parallel to the short axis of the hair; plane perpendicular to the long axis of the hair.

Tricho A prefix denoting relationship to hair.

Trichochromogenic Giving color to the hair.

Trichoclasis "Greenstick" fracture of the hair shaft. A transverse fracture of the shaft, which is splinted partly or wholly by intact cuticle.

Trichology The sum of what is known regarding the hair; the study of hair.

Trichonodosis A condition characterized by apparent or actual knotting of the hair. It is uncommon but not rare in some individuals of African ancestry or others with tightly curled hair.

Trichoptilosis A longitudinal splitting or fraying of the hair shaft. It commonly occurs at the distal end and is often referred to as "split ends."

Trichorrhexis A condition in which the hair breaks off.

Trichorrhexis Invaginata A hair disorder in which the hair has indented and the shaft has folded into itself, having the appearance of a ball and socket; "Bamboo hair."

Trichorrhexis Nodosa A condition that appears along the hair shaft as small, beaded swellings associated with a loss of cuticle. The expanded areas are composed of frayed cortical fibers through which the hair readily fractures.

Trichoschisis A clean, transverse fracture across the hair shaft through cuticle and cortex, as is associated with a localized absence of cuticle cells.

Trichosiderin Formerly, an iron-containing pigment found in normal human red hair. It is now thought to be fragments of the pigment phaeomelanin.

Undullating Macroscopic — A smooth wave-like hair form (as opposed to the abrupt form of hair buckling). Microscopic — Refers to a wavy form seen microscopically which is accompanied with true variations in hair shaft diameter.

Variate The descriptor for any of the various forms of each macroscopic or microscopic characteristic observed in human hair. The variate may be continuous, discontinuous, or a measured value.

Variate Class Limit The upper or lower limit of a continuous variate class. For variates with two classes, the upper limit of the lower class and the lower limit of the upper class is the same, i.e., divides the population of continuous variates into two classes.

Vellus Fine body hair that is present only until puberty.

Weathering The effect of the environment on the hair shaft; wear and tear that causes damage to the cuticle and cortex.

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