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HUMAN HAIR STUDIES*

1. General Considerations of Hair Individualization and Its Forensic Importance

Paul L. Kirk†

Human hair unquestionably figures as a clue or possible clue in a very considerable percentage of crimes, particularly those of violence, but only slightly less in crimes of stealth, since most individuals have a greater or less tendency to lose hairs unconsciously and at random. It is indeed strange that so tempting a type of evidence should have been so indifferently treated by criminal investigators. Some criminologists have expressed confidence in their ability to determine the source of a hair, but usually without benefit of adequate study and by methods that are not generally known. The common attitude is well expressed by Sydney Smith (1) who states, "If a definite answer is required as to whether a certain sample of hair is that of a certain individual, the investigator is strongly advised to refuse to go further than to state that the hairs are similar". Without question, present knowledge justifies such a statement to a very considerable extent, but to accept this view fatalistically as the last word on the subject is as strange as the attitude taken by many toward fingerprints in the early days of development of that important branch of criminological knowledge. To the best of the author's information, the investigation as to

whether a suspected hair belongs to a particular person is rarely carried further than to observe its most obvious properties, such as its color and its length, points which are obviously of very limited value. This is even more surprising when most criminal investigators are well aware of the possibilities of distinguishing the animal species of the hair, and spare no pains in enlarging, sectioning, and otherwise investigating the hair from this standpoint. This phase of hair study has undoubtedly been inspired by such excellent investigations as those of Glaisner (2), Hausman, (3) and others.

Some investigators (1, 4) go further and claim to determine age of human hair by such methods as measuring the rate of solution of a hair root in caustic potash. It would seem at least as difficult to accurately determine the age as to determine the individuality of the hair, if there is any analogy to other bodily structures such as friction ridges, or the physiogomy.

While thorough studies of the individualization of human hair have not been reported, the total amount of hair investigation which has been published is very impressive. Without attempting to completely review the literature, some of the more recent and outstand-

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ing contributions are here listed. Hausman (3) has contributed an extensive series of papers on this subject, chiefly from the anthropological point of view. Trotter (5) has made valuable systematic studies on human hair and has reviewed the classification of hair (6) quite thoroughly, along with an excellent bibliography. Another recent study of classification was made by Eddy (7). Methods of examination of hair have been discussed by Roig (8), Harvey (9), Fiale (10), Bellamy (11) and others. General discussions of the forensic importance of hair and its study are included in most books on criminology and forensic medicine, including Smith and Glaister (12), Soderman and O'Connell (13), Smith (1), Danforth (14) and other similar references. Older work which has often been quoted but is frequently inaccurate and occasionally misleading is that of Lambert and Balthazard (15).

Since it is a matter of common observation that an individual's hair is usually more or less distinct in appearance from that of other individuals, it appeared well worth investigating to ascertain if there are differences which are sufficiently fundamental and of sufficient magnitude to lend a reasonable probability to an identification of a person from one or more of his hairs. In this series of papers it is hoped to report studies of various observable and measurable differences of hair in sufficient numbers that statistical analysis may be employed to determine the exact variations of each of these fac-

tors which may be significant in determining individuality.

Early results of these studies appear to point very definitely to the possibility of making such identifications with a very considerable degree of probability. It has, for example, been customary for some years to require all students of criminological science in the author's laboratory to identify a single hair from one of twenty samples, all of similar color and from individuals of similar age. To the present, no such student who has completed the routine examination has failed to report the identification correctly. While this falls far short of placing a hair on a single member of the world's population, it must be remembered (a) that twenty suspects in a single crime is rather an exceptional number; (b) that the eliminative value of a failure to identify the hair as that of any of the suspect's is great; (c) that time imposes on students a restriction on the total number of hairs that can be examined, and it is impossible as yet to say whether they could equally well pick, e.g. from 100 standards; (d) that in any random group of suspects there would be greater normal variations than are present in the selected group of similar hairs used for this exercise; and (e) that the students in question have never before examined hairs and are in no sense experts in this examination.

In addition to the question of locating from which of a number of hair samples a single hair has been taken, a considerable number of criminal

cases involving human hair have been investigated with results that are, to say the least, gratifying. In one case, two fugitives from justice were located exclusively on the basis of a single hair contained in the hat of one of them which had been lost in flight. The identification in this case was later confirmed by fingerprints. In another case, hair believed to have come from the victim of an assault was located in the lodgings of a suspect, while hair diagnosed as that of the suspect was located on the victim. The diagnosis was confirmed by a plea of guilty. In another case, the identification of the hair of a suspect was confirmed by sufficient additional evidence of other types that a jury found the suspect guilty. In these as in other cases, the individualization of the hair has without exception been confirmed when there were independent means of obtaining confirmation. It would be imprudent to conclude that the procedure may for this reason be made infallible, but the results certainly justify further studies so that as high a degree of probability as possible may be attained in hair identification. At the very least, it is surely possible to develop the technique to the point of making it a valuable addition to criminological methods.

Technique of Examination

The total possible number of factors which might be studied in connection with human hair identification are very large. Only those which have so far proved to be of value will be briefly described here, though undoubtedly many more will ultimately prove useful as

well. In order to make examinations of hair, certain routine matters of handling and preparation must be considered.

If the bodily origin is definitely known it must naturally be recorded, even to the extent of distinguishing between crown, nape and sideburns or temples of human head hair. Other body hairs need not be considered here for they have not been studied to the extent of making individualization possible as yet. Naturally it is necessary to be able to distinguish body hairs from head hairs, a matter which is usually simple to the person who has had some experience in hair examination. It is as yet uncertain whether hair from different portions of the head shows consistent differences which are significant, but the distinction of areas should be made until evidence is obtained to settle the point.

The head hair is first examined without any cleaning or other treatment by placing it on a microscope slide, cover with a cover slip and examining it under magnification. At times there are particles of adherent matter which may be significant. Ordinarily the debris is merely a mixture of dandruff, oil, and common dust. After determining the importance of the debris, the hair is washed thoroughly in a mixture of equal parts of ether and alcohol in a covered dish. This washing should be continued with agitation for about 15 minutes, or even longer when preparing it for the measurement of such properties as refractive index. In the latter case it is sometimes necessary to

make a second washing with clean solvent to ensure absolute removal of all grease. The hair is dried in the air, preferably on a clean filter paper, and then it may be cut into lengths of about one half inch for convenience in mounting. Short hairs must be cut into still shorter pieces for it is necessary to make more than one mounting for a complete examination. In measuring some properties such as diameter, refractive index and birefringence, it is desirable to make short sections not more than 1 mm. in length. This is conveniently done by mounting two razor blades on a thin brass block, so that the edges are parallel and about 1 mm. apart. This simple device will cut any number of short sections of equal length.

A portion of the hair is mounted dry under a cover slip which is sealed to the slide with a little Kronig cement (1 part beeswax melted with 4 parts resin), taking care not to allow the cement to contact the hair. Another portion is mounted in Canada balsam. Millimeter sections are laid aside for special purposes, or else made as needed. In case the amount of hair is too small for simultaneous mountings and without balsam, the dry mount may be examined and later mounted in balsam. In case of necessity, the balsam mount may be cleaned in xylene and remounted dry.

Occasionally hair is encountered with such dense pigment that transmitted light is inadequate for its examination. In these cases the Ultropak illuminator is helpful. If the magnification must be great (e.g. 50x objective) it is some-

times difficult to find sufficiently thin cover slips to allow the objective to be lowered into focus. In this case a simple expedient is to fasten the hair to the slide by covering it with a piece of transparent Scotch tape (16). This type of mounting may for convenience be substituted for all dry mounts of hair. It has the disadvantage that if the hair is to be subsequently mounted in another way it must be recleaned to remove any adhesive from the tape. Air bubbles which are frequently trapped are another source of difficulty.

As a general rule it is unnecessary to make cross sections, in spite of the very great prevalence of this custom. In distinguishing species the cross section has a very definite value which is, however, not so great even in this case as it has been considered by some. In human hair studies, the only factors which are given by a cross section are the minimum and maximum diameters, the appearance of the medullary canal and the cross sectional pigment distribution. The first factor is readily determined without sectioning (as will be described later), and indeed, much more accurately, because of the tendency of the hair to pull in cutting the sections, thereby giving an oblique cut rather than a normal 90° section. The second factor is relatively insignificant in identification, and can also be seen in the longitudinal view, though somewhat less clearly, with transmitted light. The third factor occasionally has significance, chiefly in determining the relative central or peripheral distribution of the pigment. This can be also seen in the balsam mount by focussing

up and down and observing the shift in the maximum density of the pigment. Finally, the technique of cross sectioning is not one that can be done ordinarily without considerable experience, and to a very considerable extent it destroys evidence. For these reasons it is considered preferable to save the cross section for a final resort in case no decision can be reached without it. In the author's laboratory this has occurred just once, and in that case more experience in the lateral examination would undoubtedly have settled the point.

Necessary microscopic observations may now be made on the mounted hairs in any way desired. The use of magnifications greater than about 500x is generally useless. The increased thinness of the field and the poorer resolution with higher powers more than offsets any advantage of greater magnification. The single important exception to this statement is the detailed examination of the pigment granulation which must often be performed with oil immersion objectives. As indicated above, the use of the Ultropak illuminator is sometimes highly advantageous, particularly for examination of the cuticle layer, but also for deeper structure in many instances. For example, the medullary canal is very easily observed under this instrument. Study of pigment distribution is generally made with transmitted light.

Characteristics for Study

Almost an unlimited number of characteristics and sub-characteristics of hair may be studied and at present it is

not only impossible to say how many of these are subject to investigation but also how significant any of them may ultimately be found. Those which have proved of value up to the present will be listed here and discussed.

Morphological Factors

1) *Color*. This factor is the most obvious one to the inexperienced individual as well as to the expert. Its interpretation, however, must be made with caution. Certainly when gross differences are found in the color of two hairs, it is a fair assumption that they did not have a common origin. This is particularly true when the actual color rather than the shade or hue is different. But experience shows that different hairs from the same head will frequently have rather wide variations in color, making necessary a careful scanning of many hairs of the individual furnishing the standard. This is especially true with blond hairs. Only if the color of the questioned hair falls within the known range of the standard is this factor significant. If it falls without, it is left to the investigator to be sure that his standard is really representative. Nevertheless, in a majority of cases the differences of color may be legitimately used for preliminary elimination.

It would be highly desirable to establish an absolute color chart for hair (11) and in addition to make accurate studies of the characteristics of hair pigments in order that their chemical identity or difference might be determined as a check on the color alone.

2) *Diameter*. Since human hair is

nearly always oval in cross section rather than round, it is necessary that the two extreme diameters be determined before any significance other than a gross idea of the hair coarseness may be attributed to the measurement. An accurate cross section undoubtedly allows the simplest measurements of minimum and maximum diameters. Since it is so difficult to obtain such sections, the technique employed in this laboratory is to use millimeter sections which have been cut as previously described. These are placed on a slide which has been slightly frosted by gently rubbing two slides together with a little fine, moist carborundum powder between them. Such a short section will in nearly every case lie in its stable position, *i.e.*, with the broad diameter parallel to the surface of the slide. A calibrated ocular micrometer may then be used directly to obtain the maximum diameter, and a calibrated fine adjustment on the microscope will give the minimum diameter. For the latter measurement the instrument is first focussed sharply on the frosting of the slide, and the fine adjustment micrometer is read; then it is focussed on the very top of the hair section and read again. With care this method gives results nearly as accurate as those read from the cross section but with much less effort, and avoids the important possibility that the section is not cut exactly across the hair.

The significance of diameter determinations in individualization of hair does not appear from preliminary observation to be very great. Certain individuals have relatively uniform diam-

eters throughout their hair while others show great variation. One case studied showed a three-fold difference in both minimum and maximum diameters between his smallest and his largest hairs. If sufficient hairs are available for study, this variation itself should be significant, *i.e.*, a person with uniform diameters could be distinguished from one of very non-uniform diameters. Many data will need to be collected before any absolute significance may be ascribed to this factor. For the same reasons, the index of curvature, $\frac{\text{small diameter}}{\text{large diameter}}$ is variable from hair to hair and from point to point on the same hair, though it is probably true that the average of a large number of measurements, and possibly the range of variation, may be shown to be significant for individualization as well as for racial characteristics.

3) *Scale Count.* By scale count is meant the number of scales intersecting a line laid along the axis of the hair, and of some known length. The usual technique in the author's laboratory is to move the hair so that one line of the cross hair in the microscope ocular bisects the hair longitudinally while the calibration marks of the ocular micrometer are at right angles to the length of the hair. Each intersection of a scale edge which crosses the bisecting cross hair is counted, usually over the length of the ocular micrometer scale. For comparative purposes the same micrometer and microscope are used with all the hairs in question so that no absolute calibration need be applied. For absolute data, the length of the mi-

chrometer scale is determined and the scale count corrected to that of some standard length (e.g., 0.2 mm., as used in this study).

The significance of scale count means and ranges both appear to be very definite. As eliminative factors each usually serves to reduce the number of possible hairs by about $3/4$ or $4/5$, provided enough counts are made so that the averages become reasonably significant. At least 25 counts are usually made before the average is taken, and this average is only interpreted to about $+10\%$, though the average usually falls closer than this to the grand average for the individual. More concretely, if the average scale count is 24, all hairs with averages below 22 and above 26 would be considered as definitely from another individual, and those between 22 and 23 and between 25 and 26 would be considered as improbable, but subject to further comparison. A final value for scale count average and range should be based on at least 100 counts, the averages being more closely interpretable. The statistical significance and interpretation of these factors will follow in a subsequent publication. We can conclude however, that scale count has a very considerable value both in description of hair and as an eliminative factor.

4) *Scale Picture*. By scale picture is meant the general characteristics of the scales which are observable, such as the shape, regularity or irregularity of sizes, and edges, and such other features as may be observed microscopically. These characteristics are by far the hardest to study or to discuss in a

systematic fashion, but in spite of this, they may have considerable value in hair individualization. It is observed that many hairs have regular scale structure with little variation from part to part. When this is the case, preliminary studies indicate that it is a characteristic of the individual and may be expected on all of his head hairs to a great degree. On the other hand, when the scales are irregular in size (e.g., large interspersed with small), in shape, or in contour lines, serrations, etc., that also will be found quite generally over the range of hairs from that individual. Except for the work of Eddy (8), little if any systematic study has been made of these scale properties, but it seems a subject well worth investigating, even though nothing more definite may be said than that the experienced hair examiner will be able to use the scale picture to a very considerable degree in individualizing hair. From a limited number of hairs of different origin, it has been found possible in many cases to identify unknown hairs correctly on the basis of this property alone.

(5) *Pigment Distribution*. Of the various factors utilized in individualization of human head hairs, the distribution and appearance of the pigment granules in the cortex of the hair has proved to be one of the best, if not the very best. Again, so many factors are included under the term of pigment distribution that it is difficult to discuss or adequately separate them. First might be considered *pigment density* and *density distribution*. In general the pigment density is inversely propor-

tional to the amount of light that may be transmitted through the hair under some standardized set of conditions. Where the density approaches a maximum, there is almost no light transmitted as in certain very black hairs found most often in the negro race and to a lesser extent in races of Asiatic origin. A minimum density would be found in very light blond or gray hair. The density distribution refers to the fact that in most cases the pigment granules in human hair tend to cluster close to the periphery of the hair, but this tendency varies somewhat from person to person. It may be observed in cross section most easily, but may also be studied by focussing up and down on a balsam mount of a section of the hair lying lengthwise of the slide.

Another sub-factor of importance is the distribution with respect to *size of granules*. Some persons show a relative uniformity of size which may range from so small as to be scarcely visible under high power, up to granules which are very coarse. Most persons exhibit a greater or lesser lack of uniformity of granule sizes, so that in one hair we may see all sizes of granules. However, the relative proportion of coarse to fine granules (based on some arbitrary size basis) will vary enormously between individuals, but not greatly between hairs from the same individual. This is a difficult factor to treat quantitatively though it is quite apparent to the experienced observer.

Another factor which is important and even less susceptible to exact description is the *shape of the pigment*

granules. Unquestionably the pigment granulation varies greatly between individuals with respect to the general shape of the granules which are laid down. Normally the granule is definitely elongated, so much so in some cases as to appear as a thin streak. In other cases the granules approach a roughly oval shape with a much lesser degree of elongation, while still other individuals show a definite alignment of discrete granules, giving the appearance of great elongation. A study of this factor will show quite characteristic differences between the hair of different people, particularly with respect to the coarser granules, and becoming more significant as the different sized granules are considered.

Pigment distribution, consisting as it does of these various factors may be utilized to a very great extent in hair individualization. Because of its complex nature, however, it is a factor which must be very thoroughly studied over a considerable period of time before it will yield its maximum results. It is hoped that it may be broken down into its sub-factors for study and that reproducible means may be found for evaluating each of the sub-factors.

(6) *Medullation*. The presence or absence of medulla in head hair has little significance, nor does its appearance have much more. It is true that individuals vary considerably with respect to the total medullation shown by their hair, and to this extent the factor becomes useful. Cases have been observed in which nearly every hair showed medulla and most hairs had

virtually continuous medulla. The most striking case in which this was found was with an elderly woman whose cortex was uniformly devoid of pigment.

Physical Factors

Refractive Index. As will be shown in a later paper, refractive index of hair is a characteristic of very definite value, both for individualization and for race and sex determination. The range of refractive index is consistently higher for female than for male hair, and apparently for Asiatic races than for European races. Within the same sex and racial type, the range is fairly narrow, but broad enough to cover several times the probable error, and therefore, to serve for the elimination of at least 3/4 of all possibilities. As an individualization characteristic, it is comparable in its eliminative and positive value to scale count.

Birefringence. All hairs show the characteristic of being more or less refractive, though with the exception of hairs used as textile fibers, little notice of this fact seems to have been recorded. Unlike a truly crystalline material, the lack of morphological homogeneity in the hair makes quantitative study of this property exceptionally difficult and it has not progressed to the point at which any final conclusions may be drawn. Preliminary investigation appears to indicate that this factor, too, will have a definite eliminative and some positive value for individualization when the means of studying it have been sufficiently standardized and

defined. When two hairs of the same diameter are examined between crossed Nicol prisms, it will be observed that those from different sources frequently show different interference colors, while those from the same origin will generally be of the same color. Further careful study of this property is expected to produce results of very considerable significance in individualization of human head hairs.

Miscellaneous. Many additional physical properties suggest themselves. Drawing analogies to the extensive work done with the mechanical properties of wool, such factors as *tensile strength* may be of consequence. It has been noted that permanently waved hair stretches very readily in comparison with untreated hair. This suggests the development of a method for study of the *stretch coefficient*, a matter which is receiving preliminary investigation. Virtually nothing is now known of the *electrical properties* of hair which may also prove to be of definite significance when they are studied.

Chemical Factors

It seems virtually certain that the hair will reflect differences in its chemical environment during growth. Again making use of the analogy with wool it is recognized that the cystine content varies with the nutritional state of the sheep. It is equally certain that some elements such as arsenic and probably silicon are selectively taken up in the hair. Though there is little available proof, it is obvious that hair color itself

must to some extent depend on chemical differences of the pigment, and it is equally logical to believe that at least a part of the morphological differences in hair are based on corresponding chemical differences. As previously mentioned, the rate of solution of the hair bulb in caustic potash is widely used for indicating sex of hair, and the extensive work of Tadokoro (17) and others (18) indicates that sex has a very important effect on the chemical makeup of epidermal structures, including hair. The difference in hair distribution in the sexes, as well as other similar secondary sex characteristics may be largely a reflection of the difference in the basic chemical makeup of the system exhibiting these properties.

All of these factors, and others, clearly point to a large undeveloped field for investigation in the basic chemistry and chemical differences of hair. So far as is known to the author, no chemical methods have been employed thus far in hair individualization.

Other Factors

Many factors of an artificial, pathological or accidental nature may enter in the individualization of human hair. Most common of these are self imposed treatments such as artificial waving and dyeing. While such treatments are usually very obvious to the examiner and will have a greater or less significance in the individualization, the most important result is probably the altera-

tions that they produce in the other more basic factors listed for study. Permanent waving, for instance, alters many morphological factors including diameter and scale count, and physical properties such as birefringence and tensile strength. Dyeing naturally alters hair color, but not pigment color, while bleaching alters the latter as well.

Various diseases affect the growth or permanence of the hair. To what extent such alterations as are produced by disease may be expected to alter the morphological, chemical or physical properties has not been established, but it is scarcely to be doubted that there are such effects. While a complete study of hair must take into account all such factors as the above, their criminological importance is probably not great except in instances involving a long lapse of time between time of collection of questioned hair and of standard.

The large number of morphological, physical and chemical factors which may be studied in hair investigation, and the preliminary indication from a study of a few of these factors definitely points to the possibility that human head hair may be positively individualized and used in personal identification. Before such identification can be considered as definite, large numbers of data must be collected and analysed statistically.

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[The second paper of this series (II. Scale Counts) will appear in the next issue of this Journal.]