Nicholas Petraco,[1] *M.S.; Charles Fraas,*[2] *B.S.;*
Francis X. Callery,[1] *B.S.; and Peter R. De Forest,*[3] *D. Crim.*

The Morphology and Evidential Significance of Human Hair Roots

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ABSTRACT: A discussion of the morphology of human hair roots is presented. In addition to descriptions of variants of the root appearance for hairs removed from follicles in the three classical growth phases, several other commonly occurring root configurations are described and illustrated with photomicrographs. The possible evidential significance of each in certain case situations is discussed.

KEYWORDS: criminalistics, hair, microscopy

Hair figures prominently as significant evidence in many criminal and civil investigations. It is readily transferred during interactions among people and other surfaces. For this reason it is useful in investigating questions involving associations among people, places, and things. Thus, normally the forensic scientist is concerned with the question of commonality of origin and directs his/her efforts toward attempts at hair individualization. This question is addressed through the comparison of human hair using microscopical hair comparison techniques. The hair comparison process is difficult and rarely provides evidence that can stand alone. Conclusive evidence of an association based on a single-hair comparison requires independent corroboration. Although many instrumental approaches to the individualization of human hair have been tried in recent years, these have not proved to be useful or reliable. Perhaps further work will bring about an improvement in this situation. However, for the present at least, microscopic morphology remains the primary means of approaching this difficult problem.

In some case situations, other aspects of hair morphology which may not be especially relevant in the comparison process per se, may overshadow the value of the comparison of inherent features of the hair and perhaps serve to complement or contradict it. Thus, in addition to the goal of approaching individualization, other questions can be addressed through microscopic morphology.

Root morphology can be important in many situations. Although several previous publications have dealt with root morphology and its evidential significance, they have focused on

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[1]Detective-criminalists, Crime Laboratory, New York City Police Department, New York City, NY.
[2]Detective-criminalist, Scientific Investigation Bureau, Nassau County Police Department, Mineola, NY.
[3]Professor of criminalistics, Department of Sciences, John Jay College/CUNY, New York, NY.

differences among hairs from the three primary follicle growth phases [*1-6*]. These are the anagen, catagen, and telogen phases. In the anagen phase the follicle is fully active and is producing hair at the rate of about 3 mm/week. Follicles typically remain in the anagen phase for a few years, after which time they enter the transitional catagen phase, where preparations are made for a cessation of activity. When the activity has ceased, the follicle is said to be in the telogen or resting phase. It is clear from steady-state considerations that the percentage of time that a follicle spends in each phase is proportional to the percentage of follicles in each phase at any given point in time. Typically, roughly 80% of the follicles will be in the anagen phase, less than 1% in the catagen phase, and approximately 20% will be in the telogen phase. A nongrowing hair may remain in a telogen follicle for a period of several months where it is held in place mechanically because of an enlarged keratinized bulb which anchors it in the mouth of the follicle. If such hairs are not shed before the resumption of follicular activity at the end of the telogen phase, they often would be shed at this point. In some cases, when the resting follicle resumes activity, a new hair is produced which emerges adjacent to the existing telogen hair.

Few researchers have published data on the occurrence and evidential significance of other commonly encountered root configurations [*7,8*]. The objective of the present study is to help fill this gap in the literature. This discussion will focus on aspects of root morphology that can be of value in forensic science investigations.

For the purpose of clarification and review, the appearance of human hair roots representing the three primary growth phases of the hair follicles (that is, anagen, catagen, and telogen) will be discussed first. These terms will be used as adjectives to refer to hairs from follicles in the respective stages of activity. Next, the appearance of the proximal ends of hairs exhibiting several different root configurations will be described. The configurations to be examined and described will include the following: anagen hair with no root sheath, telogen roots with follicular tags, postmortem root banding, and advanced postmortem decomposition.

Procedure

Several hair specimens were chosen from hundreds of casework samples. Each hair specimen was mounted in either Permount®, having an approximate refractive index (RI) of 1.525 at 25°C, or Meltmount® 1.539, with a refractive index of 1.539 at 25°C. Meltmount 1.539 is a newly available material with certain advantages for mounting hairs in forensic science casework [*9,10*]. The hair specimens were then examined with normal brightfield and polarized light microscopy (PLM) at magnifications ranging from 24 to ×400. The morphologies of the various root configurations were studied and classified.

Results and Discussion

Anagen Hairs

Figure 1 shows a typical anagen root with a complete external root sheath attached. When an actively growing hair is plucked with a rapid motion, the external root sheath usually accompanies it and remains affixed to it, although there is some variation from individual to individual [*5*]. Once the root sheath dries out, it becomes rather brittle and can be dislodged from the hair shaft and possibly lost. This is to be guarded against, because a number of techniques can be applied to the root sheath which are not possible with the hair itself (for example, isoenzyme typing and sexing).

From an examination of Fig. 1, it can be seen that the root sheath is clear and transparent and that the pigment granules in the hair shaft extend all the way down to the root bulb. The pigment producing cells (melanocytes) produce the melanin pigment in melanosome organ-

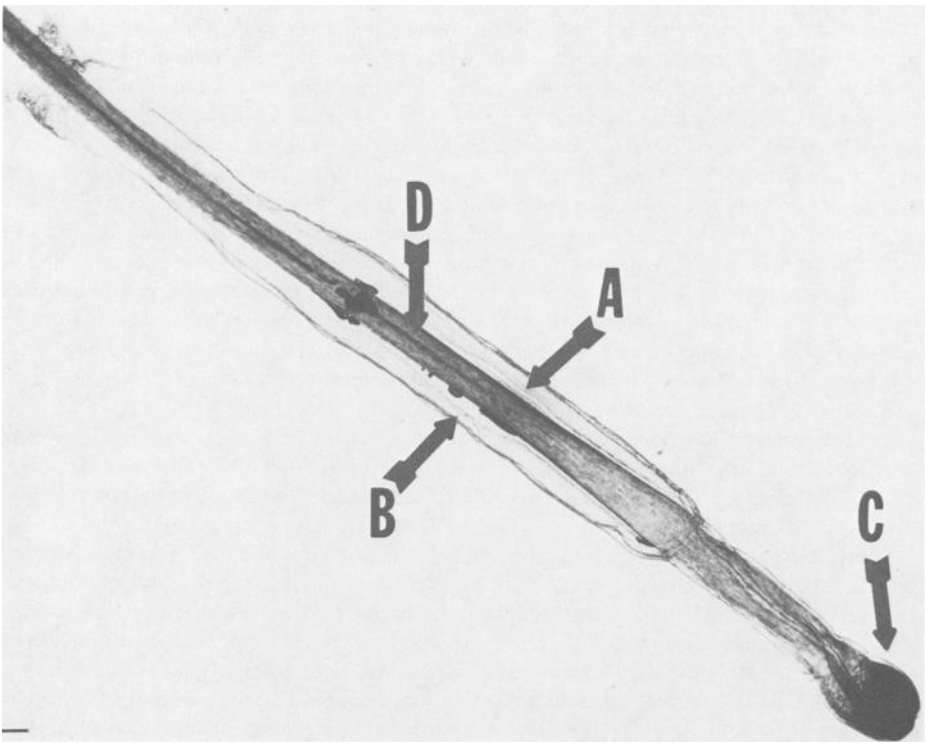

FIG. 1—*Typical anagen root configurations obtained when a hair is rapidly plucked. Note clear transparent root sheath and its inner* (a) *and outer* (b) *portions. Roots bulb* (c) *and hair shaft* (d) *are quite evident. Note continuation of pigment granules right down to root bulb. The black bar equals 100 μm.*

elles in the bulb area where the hair is being actively produced and distribute them among the developing cortical cells.

The anagen root with the root sheath attached is often present when a hair has been "forcibly" removed such as might take place in a struggle. This may at times also be accompanied by signs of strain along the hair shaft such as twisting, crimping, or looping as seen in Fig. 2. Or there may be residual stretching or "necking down" in the nascent hair in the root area. Considerable caution regarding interpretations that a hair was "forcibly removed" must be observed [*5,11*]. There are numerous ways in which an anagen hair can be removed in normal activities which do not involve a "struggle."

In cases involving the removal of large numbers of hairs during a violent struggle, hairs exhibiting the characteristic root morphology of all three of the normal growth stages may be present. Hairs displaying telogen and catagen root configurations are also seen in naturally shed hair and in hairs that have been removed by combing, brushing, or massaging.

Catagen Hairs

Figure 3 depicts roots from both the catagen and telogen growth phases. Note the dried-up root sheath and the club shaped base of the hair on the left of this figure. This has a common root sheath as manifested in an early catagen (transitional) hair. An outline of the developing telogen root bulb is easily seen inside the dried-up root sheath. In the catagen growth

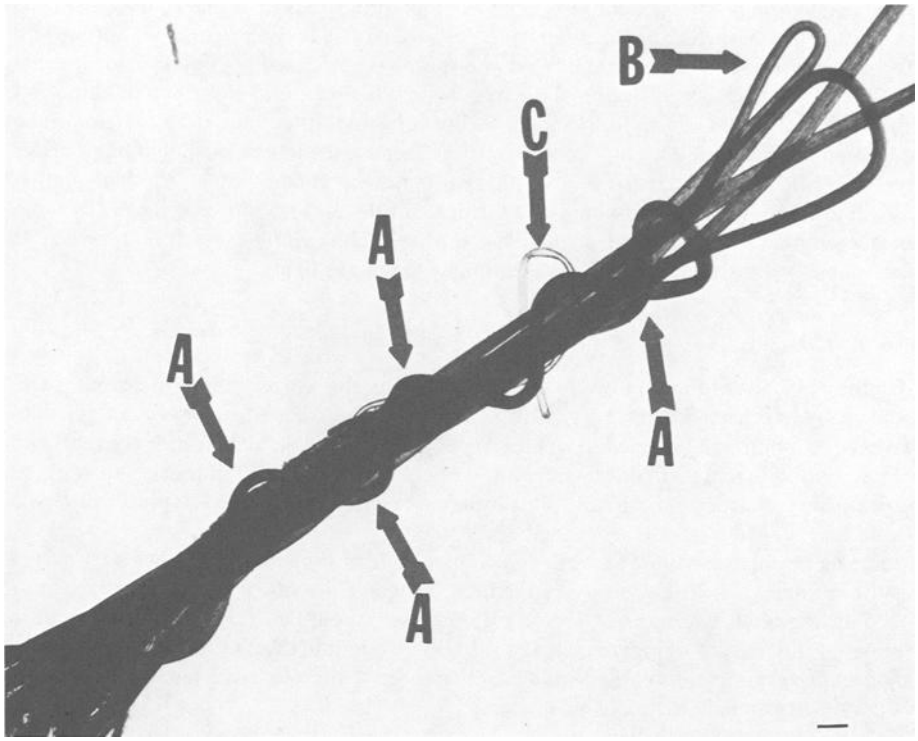

FIG. 2—*Signs of strain in upper hair shaft above root:* (a) *twisted and crimped, and* (b) *looped. Fibers* (c) *and other debris can also get entangled during a struggle. The black bar equals 100 μm.*

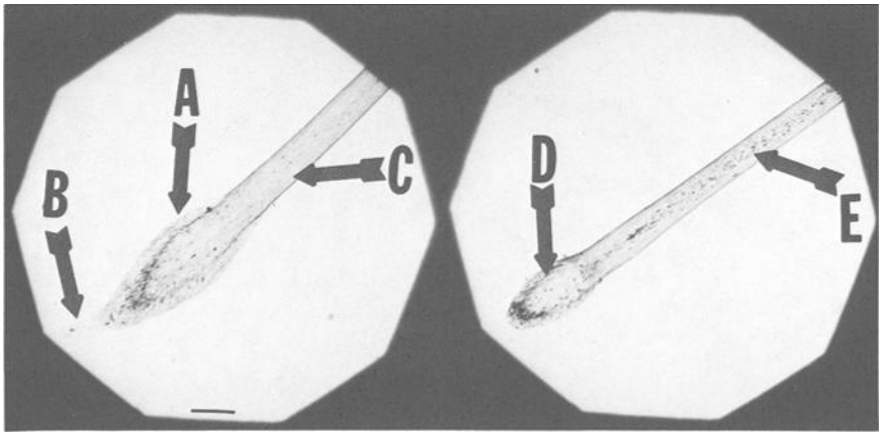

FIG. 3—(Left) *common catagen root configuration. Note root sheath* (a), *club* (b), *and sparse amount of pigment just above the root bulb* (c). (Right) *typical telogen root configuration. Note pear shaped bulb with no root sheath* (d) *and large number of cortical fusi just above the bulb. The black bar equals 100 μm.*

phase, the density of the pigment just above the root bulb is less than that in the rest of the hair shaft. This characteristic is caused by the cessation of activity of the pigment producing cells (melanocytes) as the hair follicle goes into this phase of growth. Normally, the medulla (air filled) is not produced during the catagen growth stage, and therefore, is often not present just above the root bulb. It should be borne in mind that hairs from follicles in the catagen phase can exhibit a range of appearances because the follicle is undergoing a series of rather rapid transformations as this phase progresses. There is no sharp demarcation between the end of the anagen phase and the onset of the catagen phase or the cessation of the catagen phase and the start of the telogen phase. Thus, early catagen hairs resemble anagen hairs, while late catagen hairs are similar to telogen hairs.

Telogen Hairs

On the right side of Fig. 3, the root end of a hair from the telogen phase (quiescent stage) is shown. A hair removed in this growth phase has no root sheath, no pigment granules above the root bulb, and no medulla on the lower portion of the hair shaft near the root, and it usually exhibits a higher concentration of cortical fusi (air spaces) in the area just above the pear shaped hardened root bulb. This is the root configuration that is typically observed when a hair is shed naturally from the body.

Some hairs which are plucked while in the anagen growth phase exhibit only partial root sheaths or none at all. It has been observed that anagen hairs which have been removed by slow plucking often have no root sheath [5]. However, these hair specimens still exhibit a continuous distribution of pigment along the hair shaft right to the base of the root. Further, they often have minute bits of tissue and blood attached to their outer surfaces, as illustrated in Fig. 4. They are still distinctly anagen hairs.

Telogen roots from fleshy body areas such as the pubic or facial regions often demonstrate follicular tags (see Fig. 4). This root morphology could be confused by some examiners with that of hairs plucked from follicles in the anagen or early catagen growth phases. However, the lack of pigment and the presence of cortical fusi just above the root tag are characteristic of this type of telogen root.

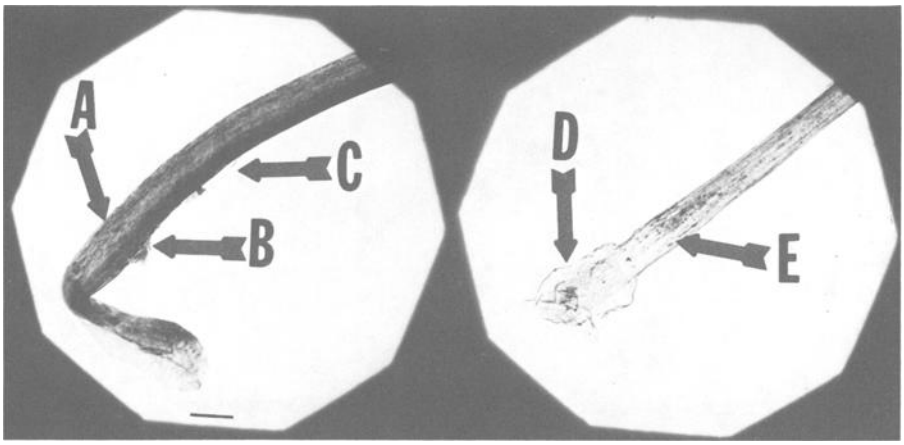

FIG. 4—(Left) *type of anagen root obtained when a hair is slowly removed—no root sheath is evident* (a). *Bits of blood* (b) *and tissue* (c) *are frequently seen.* (Right) *typical root obtained from fleshy body areas such as the pubic region. Note follicular tag* (d) *and cortical fusi* (e). *The black bar equals 100 μm.*

Other Evidence on Roots

Cytological and serological testing can be carried out with root sheath tissue. Barr bodies and Y bodies can be sought as a means of determining the sex of the donor [*12*]. In addition, several polymorphic enzyme systems can be found in this tissue [*13*]. Information derived from such testing can be a very valuable adjunct in the hair comparison process. Hairs found in the victim's hands, which may have originated from the assailant during a violent struggle, are often covered with the victim's blood or other physiological fluid. To avoid error when typing root sheaths, it is imperative to make certain that there are no remnants of exogenous physiological fluid or fluids on the outer surface of the questioned hair. as shown in Fig. 5.

Postmortem Root Banding

The proximal portion of the shafts from postmortem anagen hair specimens may manifest an opaque ellipsoidal band which appears to be composed of a collection of parallel elongated air spaces and is approximately 0.5 mm above the root bulb and about 2 mm below the skin surface. These types of roots and those evidencing more advanced decomposition are collectively termed a "putrid" root in the terminology proposed by the Committee on Forensic Hair Comparison [*14*]. We refer to the former as "postmortem root banding." The enclosed air is what makes this banded area of the hair appear opaque in transmitted light. The same band appears bright when incident illumination is employed with the microscope.

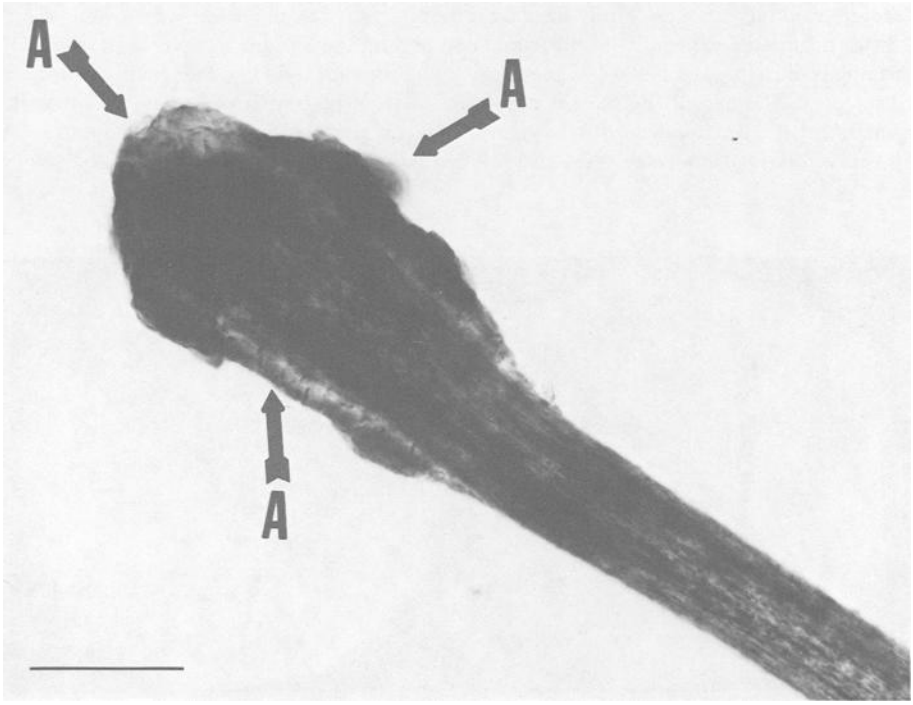

FIG. 5—*A hair recovered from right hand of a woman who was bludgeoned to death with a hammer. The root portion of this questioned hair was covered with victim's blood* (a). *The black bar equals 100 μm.*

If the banded area is sliced open with a razor blade and mounted for study in transmitted light, the mountant can enter some of the air spaces. When this happens, this portion of the band becomes transparent. Evidence of the parallel elongated voids making up the banded area can be seen in scanning electron micrographs of bands which we have cut open. The banding phenomenon has been observed in hair specimens with anagen root configurations, which have been removed at autopsy from individuals who were dead for as little as 8 h, although it is more typical of longer exposure. More research will be necessary to elucidate those conditions under which these changes can take place. Factors such as the manner of death may even have an influence.

It appears that this particular zone of the hair is especially prone to degenerative changes. Above this zone the hair is more fully keratinized and stabilized by disulfide cross-links. Areas below this point are deeper in the skin and are thus afforded a degree of protection not available to more distal areas. Perhaps predictably, this banding phenomenon does not occur anywhere nearly as early, if at all, with the shafts of fully keratinized telogen hairs. The exact composition of this band and the mechanism or mechanisms that produce it remain unknown.

It is believed that, with further research, this phenomenon might be a useful adjunct in helping to establish the time of death as well as some other facts of the case. Shed hairs with this root feature in trace evidence taken from the home or vehicle of a defendant would suggest that a body several hours or days old had contributed these hairs. Such a finding could provide strong complementary evidence to positive associations made during normal hair comparison work. For example, in cases involving the suspected killing of a spouse, the finding of hairs matching the missing or murdered spouse in the family home or vehicle would be expected and would only serve to show that the spouse had been present at these locations. On the other hand, the finding of such hairs with anagen roots evidencing signs of decomposition in the scalp would have a profound impact on the case.

With protracted exposure, the proximal end beyond the band is lost. In Figs. 6*a* and 7, banding is illustrated. Figure 6*b* depicts the typical proximal end of a hair found with skeletal remains. The end of the shaft is devoid of any root bulb, or tissue, and the brushlike appearance of the exposed cortical cells composing the hair shaft is evident [*15*]. This type of brushlike root is also seen in cases of advanced body decomposition and is suggestive of a

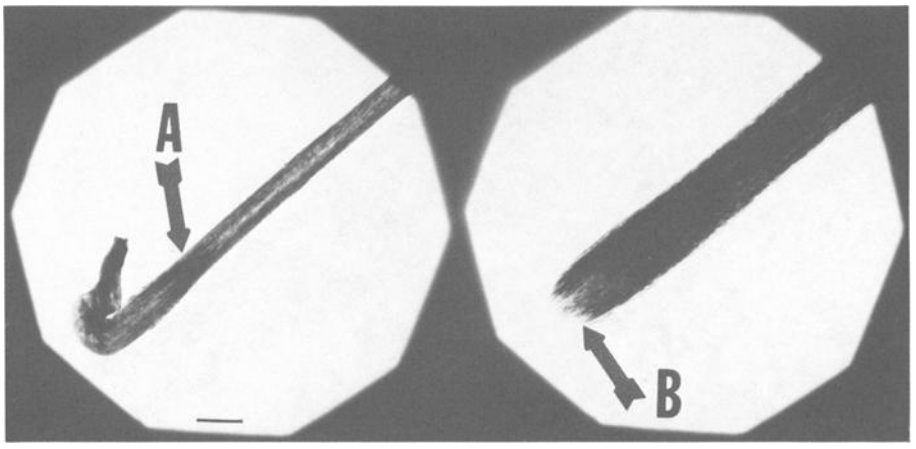

FIG. 6—(Left) *anagen root from hair sample removed during autopsy. A black band* (a) *is seen approximately 500 μm above the bulb.* (Right) *proximal end commonly seen in skeletal hair or in advanced decomposition—note brushlike appearance* (b). *The black bar equals 100 μm.*

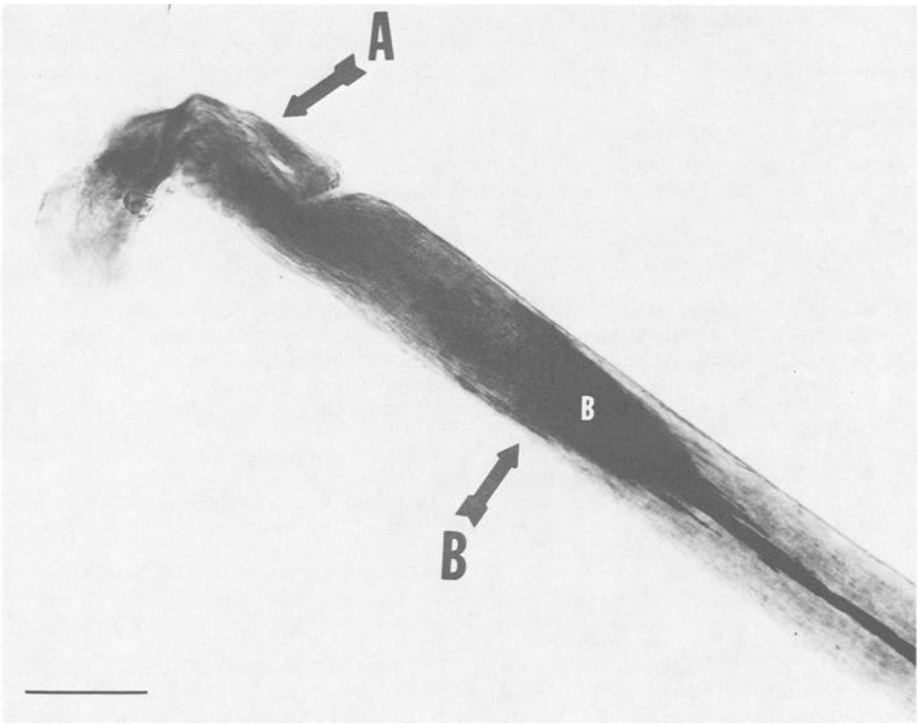

FIG. 7—*Anagen root from hair sample* (a) *removed at autopsy from a young female who was dead for approximately 10 h at the time of postmortem examination. A black band is evident* (b). *The smaller white letter B marks the center of the band. The black bar equals 100 μm.*

cleavage of the hair shaft at the location of the opaque band followed by various degrees of additional decomposition. Telogen hairs are much more resistant to localized degradation of this type.

In a recent case, a husband was accused of killing his wife and disposing of her body in a lake after running it through a wood "chipper" obtained from an equipment rental establishment. Anagen hairs recovered from the lake a month or so after the event exhibited banded roots. Because of a lack of experimental data, it is not possible at this point to determine whether or not the banding observed was due to decomposition of the body for a significant number of hours before disposal or changes taking place in hairs remaining in fragments of scalp. There is a clear need for more data in this area.

Conclusions

The evidential significance of each type of root morphology encountered in casework should be considered and, if warranted, investigated. The various human hair root configurations can provide the forensic scientist with vital investigative information. Therefore it is crucial that the root portion of any questioned hair specimen be carefully scrutinized during a forensic hair examination. The data collected can have an important role in helping to reconstruct the crime. It is clear that more research is indicated before the full potential of hair root morphology in forensic science investigations can be realized. However, it is hoped that the material presented here will prove useful in casework situations and serve to stimulate further research. The results of ongoing work with root decomposition in situ under

controlled conditions will be reported later. Certainly, many additional studies will be necessary.

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Address requests for reprints or additional information to
Nicholas Petraco, Detective/Criminalist
New York City Police Laboratory
235 E. 20th St.
New York City, NY 10003