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Postmortem Microscopic Changes Observed at the Human Head Hair Proximal End

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ABSTRACT: Only two types of human hair roots (proximal ends) derived from decomposing scalps are reported in the literature. The most common representation of the putrid root includes a postmortem dark root band in published photomicrographs. In this study, 22 cases were reviewed in which there was reliable time of death documentation from medical investigator reports. A review of these cases finds that the most common putrid hair proximal end change does not contain the postmortem root band. Four primary types of hair proximal end postmortem change were identified. This study finds no correlation of time of death with scalp hair proximal end decomposition. In addition two examples are presented that suggest that hair roots do not decompose after fresh removal from the scalp and exposure to the outside elements.

KEYWORDS: forensic science, hair biology, hair root morphology, postmortem root banding, putrid hair root, hair decomposition, forensic anthropology, time of death, hair DNA, hair diseases

Forensic examiners may be asked to determine if a found hair originated from a decomposing body. A paucity of literature exists regarding the microscopic changes that occur at the human hair root in the decomposing scalp. The one paper that gives the most attention to this subject describes "postmortem root banding" and a "brush like" proximal hair end as the two types of microscopic appearances seen when examining head hairs from deceased persons (1). Another paper reports the artificial creation of a postmortem morphologic appearance (root band) in an anagen hair root after it was subjected to Proteinase-K digestion (20 mg/mL, 4 h at 56°C) (2). A recently published atlas of hair microscopic characteristics shows a photomicrograph of a "putrid" head hair root with postmortem root banding (3). A widely recognized work regarding forensic hair microscopy simply lists "putrid" root as a type the examiner may encounter (4).

Human hair growth cycles and the ex situ microscopic appearances of antemortem and early postmortem human hair roots, or proximal ends, have been described in numerous forensic references (1–4). There are, however, no references for detailed descriptions of hair root decompositional changes. Mechanisms suggested for these postmortem changes include autolysis and microbial action (1). At least one study reports microscopic fungal changes in buried hair shafts and microscopic insect feeding changes on hair shafts (5). Several sources investigate the keratinolytic effects of dermatophytes (6). While hair examiners recognize several morphological changes in hair roots from decomposing bodies, a detailed review of and classification of postmortem changes cannot be found in the forensic literature. In order to better characterize the morphologic appearance of postmortem hair proximal end changes, and to determine if observing such changes may be helpful in estimating postmortem interval, we reviewed hair samples from selected autopsy cases with known postmortem intervals.

Materials and Methods

Postmortem scalp hair samples taken from 22 Dallas County Institute of Forensic Sciences cases were examined microscopically for proximal end forms (compound microscope, transmitted unpolarized light, 10 ×, 40 × objectives). Cases were selected where an approximate time of death was known or could be determined from reviewing medical investigator reports. Glass microscope slides with head hairs from these individual cases mounted in Permount resin as recently as 1999 and as remotely as 1988 were used. Ten to 15 complete head hairs selected at random were examined for each case. Head hair proximal ends were recorded as being "N" for normal (antemortem anagen root), "A" for postmortem root band in the distal area of the hair root stem, "B" for postmortem root band in the proximal area of the hair root stem, "C" for hard keratin point with no root band, and "D" for brush like cortical fibrils (Fig. 1). No recording was made of head hairs with telogen clubs because they were found unchanged from their antemortem appearance in all cases. Hair proximal ends were photographed with a Zeiss compound microscope (unpolarized light, 10 × objective, 10 × ocular). Crime scene and/or autopsy photographs for each case were also reviewed.

One has to assume random head hair sampling from the bodies because the hairs were realistically collected by autopsy technicians during their regular duties. It is also noted that sampling may have been further affected by the fact that decomposing scalps can begin to lose hairs through skin slippage in only two to four days after death in late summer temperatures.

Results

Our findings in the 22 postmortem cases are listed in Table 1. Four types of putrid anagen/catagen hair root changes were identified (Fig. 1). Type A (distal root band) and Type B (proximal root band) were the least common types, while Type C (hard keratin point) and Type D (brush like cortical fibers) were the most common. Most cases with postmortem intervals greater than

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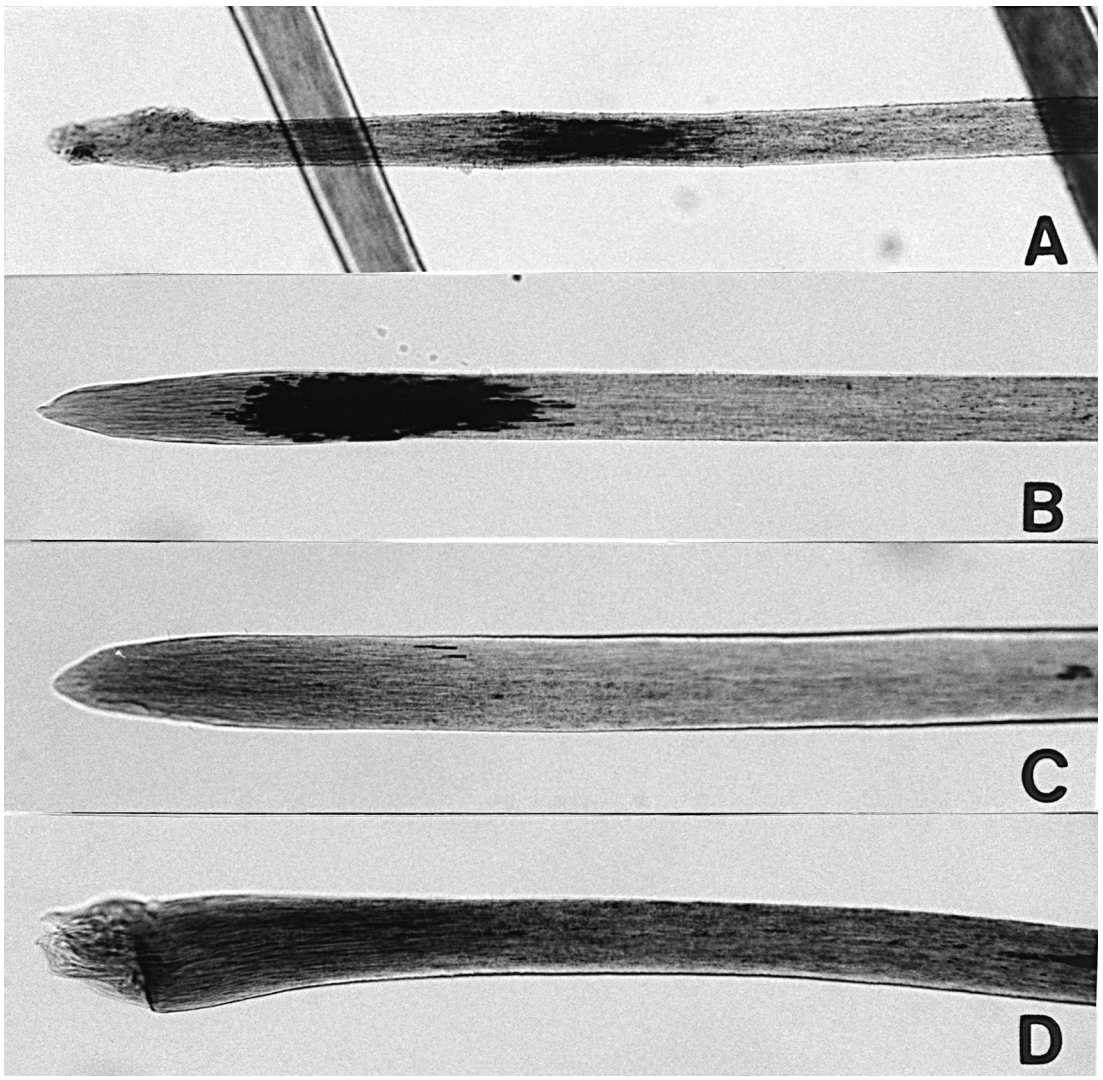

FIG. 1—*Postmortem hair proximal end change. (*A*) Root banding (distal). (*B*) Root banding (proximal). (*C*) Hard keratin point. (*D*) Brush like cortical fibrils. Unpolarized transmitted light microscopy. Permount embedding (× 500).*

about four days exhibited mixtures of postmortem hair root end morphology. Frequently, there was an admixture of putrid hairs with normal appearing anagen root ends. This type of mixture was seen in a case where the body was exposed outside for 20 days in July. (A cloth sack had been placed over the victim's head). As previously stated, telogen club hairs showed no variation from their normal antemortem appearance in all cases reviewed in this study. This suggests that only actively growing hairs (anagen) or transitional hairs (catagen) are susceptible to decompositional changes at the root.

The timing of appearance of the four types of postmortem anagen hair root change was quite variable. Early, incompletely formed, distal root banding was evident in a case with a two day postmortem interval. The body was found in a wooded area where daily environmental temperatures reached 95–100°F. Fully developed distal root bands were first seen in a case with a postmortem interval of seven days with the body found in woods where daily temperatures reached 95–100°F. This case, number ten, also exhibited the most hairs with distal root bands seen in this study. Proximal root banding (Type B) was first evident in the head hairs from a body which had been in an enclosed residence for nine days (daily outside temperatures reaching 70–80°F). Type C (hard keratin point) hairs were first seen in a case where the body was indoors in an enclosed garage for four days, with daily outdoor temperatures reaching 95–100°F. Hairs with brush like cortical fibrils (Type D) were also first seen after four days with bodies found indoors and with bodies found outside. Figure 2 shows further examples of some of the hair proximal end variants seen in this study.

A review of the scene and autopsy photographs of the decedents in this study showed variable moist and dry scalp areas. It has been the experience of these authors, who have removed and examined such hairs, that the brush like hair proximal end appeared to more commonly arise from dry scalp areas, while the hard keratin point hair ends appeared to more commonly arise from moist scalp areas.

Discussion

Although published literature implies that root banding is the "classic" postmortem hair root change, our data suggest that it is actually less common than the other types we describe. Typically,

TABLE 1—*Postmortem head hair proximal end microscopic findings.*

Race/Sex/Age	Cause of Death Crime Scene Aspects	Postmortem Interval Days		Hair Proximal End Type*
1 w / f / child	Strangled, left in pasture	0.5	Nov.	N
2 w / f / child	Mult. stabs, left in woods	2	Oct.	N
3 w / f / adult	Mult. stabs, left in bathtub	2	May	N
4 w / m / child	Blunt force injury, well water	2	June	N
5 w / f / adult	Mult. stabs, left in woods	2	July	N, early A
6 w / m / adult	Natural, in secured home	4	May	N
7 b / m / adult	Mult. GSW, left in field	4	June	N, D
8 b / m / adult	GSW, left in closed garage	4	Aug.	N, C, D
9 w / m / adult	Natural, in secured home	7	May	N
10 w / f / adult	Unk. C.O.D., found in woods	7	May	N, A, D
11 b / f / adult	Strangulation, left in field	7	Aug./Sept.	D
12 w / m / adult	Natural, in secured apt.	9	May	B, C
13 b / m / adult	GSW, partly burned	9	May	N, C, D
14 a / m / child	Unk. C.O.D., found in field	11	July	A, D
15 w / f / adult	Overdose, placed in woods	14	Jan./Feb.	N, D
16 w / f / child	Found tied, in grassy woods	14	April/May	N, A, C, D
17 w / m / adult	Stab, moved from LR to bathroom after decomp.	16	April/May	A, B, C, D
18 w / m / adult	Strangulation, shallow grave plastic bag tied over head	16	June	C, D
19 w / f / adult	Strangulation, head covered with cloth sack, left in field	20	July	N, B, D
20 w / f / adult	Strangulation, head bound with duct tape, left in field	30	Oct./Nov.	C
21 w / f / adult	Blunt force, placed in wood chipper, parts put in plastic bag	90	June/Sept.	C
22 w / f / adult	GSW, burial after embalming	16 years		C, D

* Hair proximal end types. N: usual antemortem anagen/catagen root. A: root banding (distal). B: root banding (proximal). C: hard keratin point. D: brush like cortical fibrils. Hairs with telogen clubs were seen in all cases. See Fig. 1 for A, B, C, and D putrid proximal end type(s). All cases from North Central Texas.

hairs demonstrating postmortem root banding were far outnumbered by type C hairs, type D hairs, or normal hairs. A partial explanation for the relative lack of banded hairs might be that banding can be difficult to appreciate in densely pigmented hairs (Fig. 2, *A*). Further, banded hairs may be lost from the decomposing scalp earlier than other hair root types. Nevertheless, even in cases with lightly pigmented hair, banded hairs were infrequently seen. Banding, which appears under the light microscope as a distinct opaque area within the proximal end of a hair shaft, is composed of entrapped air (1). Forensic hair examiners recognize such linear dark areas, to a lesser degree, as being indicative of an area of defective keratin filament formation in the hair cortex. Postmortem root banding typically occurs in the approximate area of the hair shaft where the sebaceous gland duct enters the follicle. Sebaceous gland secretions are formed in life by lysosomal enzymatic digestion of the interior most cells of the glands (holocrine secretion) (8). These secretions terminate the hair follicle inner root sheath by enzymatic cytolysis. Whether or not such enzymes play a role in the formation of banding is not known. Some studies confirm that laboratory enzymatic digestion can cause swelling and banding of anagen hair proximal end material (2,7). Decompositional changes in tissue are usually the result of multiple environmental, microbial, and autolytic factors.

Whatever the mechanism of postmortem hair banding, the process seems to occur at a location near the transition between the prekeratinous and hard keratin zones of the hair root. When a plucked postmortem banded hair contains the deep portions of the root stem (anagen bulb, elongation zone, and prekeratinous zone), the band is "distal" (Type A). In contrast, if a postmortem banded hair is removed from a scalp with no deep portions remaining attached, the banding is at the proximal end of the hair (Type B). Although our data suggest that it may take several days to develop postmortem banding, it has been reported as occurring in as few as 8 h (1). Why only a select few hairs demonstrate root banding is not known.

Perhaps the presence or absence of banding depends on the particular growth stage of the hair, with banding occurring only in decomposing late anagen/early catagen hairs. Telogen hairs with intact clubs from advanced decomposition cases remain identifiable by unpolarized transmitted light microscopy. This relative immunity to change is due to keratin content of the telogen club and the hard keratin content of the adjacent shaft (1,2). Apoptosis, or programed cell death, begins in the late anagen/early catagen stage of the living hair cycle and results in a shortening of the anagen root to one third it's former length to form the telogen club. When catagen supervenes the hair root stem gradually retracts upwards towards the hair root bulge and the external root sheath is shrunk by apoptosis. The lower end of the hair stem/shaft comes to rest, surrounded by trichilemmal keratin, as a club or telogen resting hair at the level of the root bulge. This means that head hair proximal ends are in varying depths of the scalp tissue at the time of death, with active anagen roots being the deepest. Precortical cells in the hair root stem contain increasing amounts of keratin fibrils and become more resistant to enzymatic digestion as one goes from the root proximal end upwards (2). The decomposition process appears to mimic the natural apoptosis process at the hair root stem except that no telogen club is formed at the end of decomposition. The keratin of the telogen club is like human nail material and is likewise resistant to the decomposition changes in the surrounding tissues (9). It may be that the anagen hair, which far outnumbers the other hair

growth stages present in the nonbalding scalp, decomposes to form the hard keratin point or the brush like ending (no banding), while the banded postmortem hairs represent the remaining minor population of late anagen/early catagen and late catagen roots which have decomposed in higher levels of the scalp tissue. It is noted that the most hairs that were proximally banded (Type B) were seen in case number 12, nine days postmortem. This male had a balding scalp. (The type C root ends, still outnumbered the type B root ends). Head hairs in balding scalps (androgenetic alopecia) spend successively less time in anagen phase than do head hairs in nonbalding scalps (10). One would expect more hairs in late anagen/catagen and telogen stages in the balding scalp than in the nonbalding scalp. Examiners should not confuse the single region of banding seen in putrid hairs with that seen in pili annulati (defect in keratin metabolism) hairs which typically present as a series of dark bands (air spaces) separated by areas of intact cortical keratin (3,4).

Type C (hard keratin point with no banding) root ends are one of the most common postmortem hair end changes, and they appear to be more commonly associated with moist decomposition. Figure 3 shows a putrid anagen root end with the remnant anagen bulb and decomposing elongation and prekeratinous zone, still barely visible, and fragilely attached to the keratinous zone. Presumably, when a head hair is removed from an advanced decomposing body, the bulb, elongation, and prekeratinous zones can remain in the scalp, while only the hair shaft with a hard keratin point is obtained. Examiners should be cautious not to confuse this pointed hard keratin stalk with pointed soft anagen bulbs (rich in nuclear DNA) (2). Proximal root banding (Type B) and hard keratin points (Type C) have not been previously described in English forensic literature. A case where two pubic hairs of a clothed decedent exhibited the hard keratin point (no banding) has been seen by one of these authors (CAL) in which there was only an approximate 8 h exposure in a 100°F temperature environment. The majority of pubic hairs in that particular case exhibited usual antemortem hair root morphology.

Type D (brush like) root ends are another frequent postmortem head hair microscopic finding. It has been the experience of these authors that such hairs seem to be more commonly associated with dry decomposition. The brush like appearance presumably results from the relative dehydration of the skin/root end, with less of a

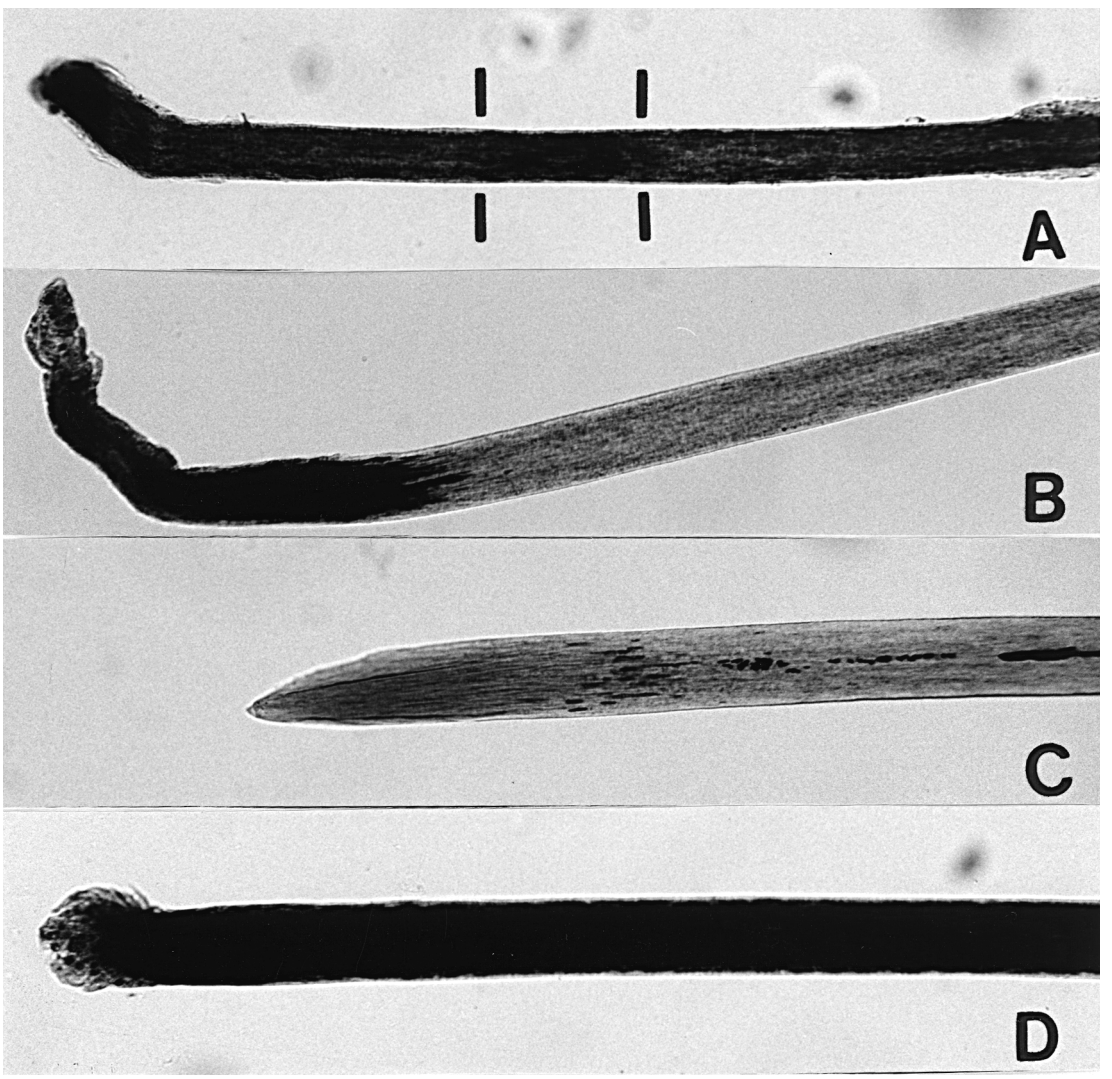

FIG. 2—*Some variants of the primary postmortem hair proximal end types. (*A*) Root banding (distal) in Mongoloid hair. (*B*) Root banding (proximal). (*C*) Hard keratin point with early/incomplete band formation. (*D*) Brush like cortical fibrils. Unpolarized transmitted light microscopy. Permount embedding (× 500).*

FIG. 3—*Decomposing anagen hair root. LEFT, Remnant anagen bulb. CENTER, Putrid zone of elongation, prekeratinous zone. RIGHT, Hard keratin point. From wet portion of scalp, black male adult, in closed garage approximately four days, daily outside temperature, near 100°F. Unpolarized transmitted light microscopy. Permount embedding (× 500).*

distinct separation of the shaft from the deep root elements than occurs with keratin point type proximal ends. Others have suggested that this microscopic appearance is caused by a breakage at a hair shaft-band junction (1). The resulting appearance is a collection of wispy fibers, reminiscent of the bristles of a brush. Examiners should be careful not to confuse this postmortem decomposition morphology with that morphology caused by significant blunt force impact or tearing forces applied to hairs antemortem. The hair disease trichorrhexis nodosa should also not be confused with this morphology inasmuch as it presents as multiple brush like breaks at the node deformation site of the hair shaft (3,4). Examiners may wish to see a combination of the more distinctive postmortem hair root types along with the brush type root prior to offering an opinion about the possible postmortem origin of a single evidence hair. This hair proximal end type would be the most problematic for examiners to form such an opinion. These authors have artificially produced brush like proximal hair ends as well as the proximal type banded root ends by digesting anagen hairs in Proteinase-K, 20 mg/mL, for 4 h, at 56°C.

Some examiners have questioned whether freshly plucked anagen hair roots may decompose and acquire postmortem proximal end appearances if left in the environment. In case number 19 (Table 1) the victim was abducted and placed alive in the trunk of her car prior to being killed and left in a field for 20 days during approximate 95–100°F temperatures. The forcibly removed anagen head hairs from the car trunk that were microscopically similar to those from the victim, showed no evidence of hair root microscopic decompositional change after 20 days in extreme temperatures. It is noted that many hairs from this victim's scalp also had the antemortem anagen root appearance along with hairs that had proximal root banding and brush like ends. A cloth sack was placed over this victim's head after death.

Further evidence of this is provided by simple experiments performed by one of our authors (CAL). Freshly plucked anagen and telogen head hairs from a living person were placed on tape and left in a wooded environment for 42 days during a January/February interval. The same experiment was repeated for a new set of head hairs that were left in the same wooded environment for 14 days during July/August (100°F temperature days). Subsequent unpolarized transmitted light microscopic examination of these two sets of hair proximal ends revealed no decompositional change. Ants, beetles, and roaches were found stuck to the tape with the hairs at the end of the July/August test. The hair follicular sheaths from this second test were dehydrated, sometimes yellowed, and sometimes cracked, but no microscopic change was seen in the hair root stem/shaft. The January/February test hairs only showed dust accumulation on the sticky intact follicular sheath. As of this writing there are no literature reports of single hair root (absent skin) decomposition ex situ.

Summary

Postmortem head hair proximal end microscopic changes are sufficiently specific for the experienced examiner to offer an opinion that an evidence hair may have originated from decomposing scalp tissue. This is especially true when numerous evidence hairs are available to examine. It is worthy to reemphasize that one cannot state that a found hair absent these putrid microscopic changes did not originate from a decomposing scalp. Postmortem banding, which may appear proximal or distal, is relatively infrequently seen, possibly because it occurs only in late anagen/early catagen, or late catagen stage hair roots. Much more common are the hard keratin points and brush like ends, both of which likely result from complete decomposition of the soft anagen hair root/stem elements which are just below the hard (permanent) keratinous shaft. The hard keratin point form is usually associated with advanced moist scalp decomposition while the brush like form is usually associated with advanced dry scalp decomposition. It is noted that one scalp can have both moist and dry areas. Although postmortem hair proximal end morphologic changes appear to be relatively specific for the decomposition process, the timing of their appearance does not appear to be helpful in determining postmortem interval.

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