Hair After Death

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Core Messages

› The hair follicle, for all its highly complex morphogenesis and life-long cycling, generates individual fibers that can (given the right conditions) persist long after the death of their host, about whom they can continue to tell tales. Much of this robustness is embodied by the unique physicochemical structure of the hair shaft which limits any significant post-biogenic change. This chapter outlines the value of hair to both archaeological and forensic investigation, specifically highlighting the significance of the incremental rate of hair growth. This property enables retrieval of detailed time-resolved information for changes in diet and physiological change, toxicology, exposure to pollutants, and use of controlled substances, in addition to individualisation using DNA.

24.1 Introduction

The scientific investigation of "Hair after Death" is one of the very few areas of human science where we can be forgiven for being a little…duplicitous, as hair fibers are "as dead" on the most active and alive scalp as they are after we have long-since passed away. By the time the hair follicle forms the keratinized hair shaft within its follicular factory, the fiber itself is effectively "dead." Biologists even refer to this process as "terminal differentiation" to hammer home the point [114, 115].

This chapter will largely focus on the terminal hair of scalp and on the fact that as the hair shaft emerges from the body it provides both a permanent record and a time-resolvable snapshot of the conditions within the body at the time of keratinization. Given that hair grows at a constant rate, this then offers a unique record of an individual's "lifeways" information [115, 127]. This is currently unavailable from any other body tissues, and as such, is of relevance to both the living and in reconstructing information once individuals die. Several key characteristics of hair growth make this a particularly attractive tissue for scientific study in archeology, forensic science, and with a potential for modern clinical benefit also. There is currently a high level of interest in the hair fiber as a biomonitor [116] of a range of exposures both during life and after death, and it is gratifying to see how what was often viewed by scientists and physicians as little more than detritus has since become something of an archive of the body's life and death experiences. Much of this relies on the unique development of hair via its highly dynamic, cyclic process of growth in which the duration of these growth cycles depends on a myriad of factors including from the more general (e.g., body site) to the most individual (e.g., age, nutritional habits, hormonal factors, and exposures) [104].

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Here, we will take the reader through some general issues relating to postmortem tissue change, inclusive of the hair follicle, followed by discussion of the biogenic change in the hair fiber associated with the nature of hair fiber growth and the survival of recovery of hair from different depositional environments. We will then provide comment on the significance of hair in the forensic sciences, its biogenic information and associated taphonomic implications (i.e., decomposition, postmortem transport, burial, compaction, and other chemical, biologic, or physical processes that affect the hair remains).

24.2 General Postmortem Change to Tissues

Our intimate personal relationship with our own mortality encourages us to view death as a single event identifiable at the critical time point. However, we also joke at being "born with the terminal disease called life!" The latter is actually much more accurate than the former view. However, when the life history of the hair follicle is considered in depth, the passing of the life force at the organismal level (viewed conventionally as irreversible heart–lung–brain failure) can be taken at the relevant point to begin our discussion of the death process. Signs of death in the total body are familiar, including total body flaccidity with all muscles relaxed, absence of breathing and pulse, dilation of pupils and skin that blanches or becomes purple. A sequence of other timed changes occurs with the passing of time, which shows both interindividual and environment-associated effects. These include a range of diagnostic death signs, including pallor mortis (paleness due to lack of capillary circulation), algor mortis (postmortem cooling), rigor mortis (death stiffness), livor mortis (also known as postmortem hypostasis), and odor mortis (death smell – a significant sign of the commencing putrefactive changes) (cf. [121]).

24.3 Soft Tissue Change in Skin and Hair Follicle

One of the most important changes upon death is the cooling of the body's tissues. Maintenance of a stable internal temperature is required to keep enzymes functioning properly in cells and tissues so that they can drive the numerous metabolic processes essential for life [110]. After death, the body's temperature-regulating systems are disrupted, and heat is lost from the body and its associated tissues. Enzyme activity begins to diminish with reduction in temperature—typically if indoors the body loses approximately 1°C/h (excluding the first hour) and reaches room temperature only after 18–24 h, dependent on ambient conditions and the condition of the corpse (cf. [110, 112]). Although some metabolic changes can occur after death, these struggle to go to completion in the absence of oxygen. Here, formation of the so-called "molecular unit of currency" of intracellular energy transfer – adenosine triphosphate – from carbohydrate/glucose is impeded [80]. Instead, this reaction is stopped at the lactic-acid stage, which builds up within cells, causing loss of several ions (e.g., potassium and hydrogen) from the cells. Moreover, lipoprotein bonds in cell membranes, among others, break further, aiding tissue decomposition. Not all cells are sensitive to ATP depletion. For example, while the mesenchymal fibroblasts of the skin's dermis may be isolated and cultured *in vitro* from cadavers of up to 48 h post-mortem, the neural-crest derived melanocyte retains viability for less than half this time [111].

During life of the organism, there is some capacity for cells to adapt (ir)reversibly to injury (via hypertrophy, hyperplasia, atrophy, and metaplasia, hydropic swelling, and fatty change) [77]. However, when an organism dies, cells react to this cataclysmic "injurious" event by being overwhelmed and so they die.

Cell degeneration after the death of the organism is termed autolysis, whereas cells that die before the death of the organism undergo generally either a process termed apoptosis (programed cell death) or a process called necrosis (resulting instead from the inflammatory responses to acute tissue injury) [73]. The tissues are lyzed by the body's own enzymes and is not associated with inflammation. Autolysis is essentially therefore the self-rotting of the tissues at the cellular level. Still, it can be very difficult to distinguish early autolysis from for example, early coagulative necrosis due to ischemia.

The rate of tissue degradation can be influenced by multiple and highly variable environmental and other factors, including temperature, bacterial activity, and degree of exposure (cf. [121]). For example, the rate of cellular autolysis and of subsequent bacterial growth which defines putrefactive change will be significantly

reduced at colder temperatures. Similarly, the rapid desiccation of tissue due either to airflow or moisture loss in arid conditions will halt microbially-driven putrefactive change in its tracks, although tissue will only undergo these steps that lead to survival if entomology is limited or excluded from the outset (see below).

The hair fiber is formed within one of the most metabolically active tissues of the body called the hair follicle [104, 117]. Thus, it can be envisaged that a significant investment of energy is required to maintain hair fiber formation at anything near its optimal growth rate (0.33 mm/day in Caucasoid type hair and slower for africoid type hair [131]). It is no surprise, therefore, that the terminal hairs of the scalp are well supplied with nutrition via a rich vasculature. Its location in the body's largest and most exposed organ, the skin, also renders it very vulnerable to the insults of the external and internal environments [117]. However, despite the destructive changes that occur to the hair follicle and soft tissues after death, its product, the hair fiber, is a remarkably robust structure. One only has to look at how the hair fiber grows to appreciate how this structure is designed to last and last.

24.4 Hair Fiber Biogenesis

Hair follicles together with mammary glands mark us out as mammals. Approximately five million hair follicles reside in our skin, although only a paltry 2% are on our heads. There is much potency in the hair "signal" for humans, and so humans have spent considerable time and effort trying to change its form for sociologic and cultural reasons [117]. The hair follicle encapsulates all the important physiologic processes found in the human body, namely, controlled cell growth/death, interactions between cells of different histologic type, cell differentiation and migration, and hormone responsitivity. This hair follicle miniorgan deserves our further admiration for its ability to intersect with the body's systemic regulatory networks, aided by its own rich vasculature and innervations [104]. Remarkably, the hair follicle can respond to most hormones known to biomedicine. Even more surprising is the hair follicle's capacity to produce for itself a wide range of hormones, e.g., sex steroid hormones, proopiomelanocortin peptides, corticotrophin-releasing factor, and prolactin [109]. Further, neuropeptides, neurotransmitters, and neurohormones are implicated in mediating hair follicle events, particularly those related to stress [118].

Further kudos can be assigned to the hair follicle as our body's only permanently regenerating organ, as it transits through life-long periods of growth (anagen), regression (catagen), and relative quiescence (telogen) [117]. Each of these stages of the hair growth cycle is variably affected by microenvironmental and systemic changes. The observation that men castrated before puberty do not go bald nor grow beards, but did so after treatment with so-called male hormone testosterone, indicated a role of androgens in hair growth [117]. Lengthening the anagen phase will lead to larger, longer, and more pigmented hairs, while the reverse will also be true. Crucially, hair follicles in different regions of the body respond differently to different androgens.

The precise nature of the "clock" controlling hair cycling has been a long enduring enigma of dermatologic research. Many hypotheses have attempted to explain this, although none can yet fully explain all aspects of the hair growth cycle. Briefly, at the end of resting phase (telogen), a unique group of epithelial cells ("stem cells") in the upper hair follicle "bulge" are activated most likely by the adjacent follicular papilla cells. This stimulation is followed by stem-cell proliferation and their progeny go on to reform the lower "temporary" part of the hair follicle in anagen. Unlike the stem cell, proliferating "transit amplifying" cells have limited mitotic (dividing) potential before undergoing differentiation.

Cutaneous scientists have more recently only begun to appreciate the hair follicle's unique immunological status [25]. Unlike the rest of the skin, the lower portion of growing hair follicles is "immunosilent" because of its lacking tissue histocompatibility antigens. While hair canals contain a resident microflora of bacteria, including *Propionibacterium acnes*, *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Demodex follicularum*, and *Malassezia* sp., the hair follicle appears to have a very effective antiinfection capacity, as evidenced by the rarity of folliculitis in human scalp, despite its 100,000 or so individual hair follicles.

While organismal death will have catastrophic implications for the skin and hair follicle preservation under normal environmental status, the hair fiber is much more resilient—although not indestructible. From an anatomic point of view, all hairs, irrespective of their caliber (diameter), length, color, or stage of

growth, are constructed of a bulk cortex surrounded by a protective covering of flattened cuticle cells [99, 117]. However, a third nonessential component, the medulla, is commonly located in the center, especially of large terminal hair fibers. The latter appears to be absent, intermittent, or complete depending on the body site of the hair (beard hair is usually medullated). This remarkable central cavity can appear with age and with pigment loss during canities.

The hair fiber is a highly integrated system of several components including in order of decreasing amount: "hard" keratins, water, lipids, pigment, and trace elements. The biosynthesis of hair proteins begins in the bulb of the growing (anagen) hair follicle, and for scalp, terminal hair follicles ceases approximately 500 μm above the zone of maximal keratinocyte proliferation. This level is still well below the skin surface, indicating that the hair fiber formation is "completed" long before it "enters the real word" (Fig. 24.1). Low- and high-sulfur proteins are synthesized here, although the synthesis of the latter peaks later. Despite significant variability the in hair form between humans of different ethnicities, chemical composition of hair protein across the ethnic groups is very uniform. There are no significant differences in amino acid composition of hair of different ethnicities [40, 117].

The "hard" hair keratins (7–8 nm across) can be distinguished from epidermal "soft" keratins by their lack of extended glycine runs. Instead, "hard" hair keratins contain many cysteine residues (particularly at the N- and C-terminal domains) that enable them to form extensive disulfide bond crosslinking with other cysteine-rich proteins. Moreover, the dynamics of assembly of keratin intermediate filaments in epidermis and hair fibers is very different. Although these filaments disassemble during epidermal keratinocyte division, they are the product of nonviable keratin-producing cortical keratinocytes in the hair follicle. To form a rigid and resistant hair shaft, abundant cysteine residues of the hair keratins need to be extensively crosslinked by disulfide bonds. Keratin-associated proteins (KAPs) facilitate such crosslinking, and various analytical tools (e.g., solubilization, chromatography, electrophoresis, and amino acid sequencing) have revealed an increasingly complex group of proteins. At least, 23 KAP families are now known, although research from the last couple of years promises to reveal even greater complexity, with large clusters of novel human KAP genes now located [117].

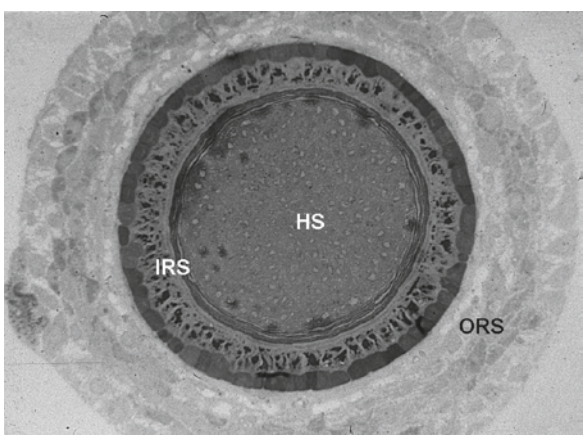

Fig. 24.1 Light microscopy view of transverse section of a human scalp hair follicle with central hair fiber (HF) surrounded by inner (IRS) and outer (ORS) root sheaths. Section was taken at the lower follicle level deep in the sub cutis of the skin, approximately 500 μm above the follicular papilla. Even at this level, the hair fiber is already highly compacted and differentiated

Lipids on the hair fiber surface (e.g., cuticle) provide a hydrophobic interface protecting the hair cortex from a hostile wet/dry environment [123]. It was not until the mid-1980s when a lipidic layer on the surface of hair fibers—termed the F-layer—was discovered, and this was found to contain a large amount (58% of total) of a methyl-branched 21-carbon fatty acid. The 21-carbon saturated fatty acid (exclusive to the hair/wool cuticle) is present in exceptionally high amounts and has been identified as 18-methyl-eicosanoic acid by mass spectroscopy. The main function of the branched methyl-eicosanoic acid is currently unknown, but it may be involved with increasing the degree of hydrophobicity over straight-chain fatty acids and/or altering the frictional quality of the fiber. In humans, the major fatty acids in hair fiber lipids include 16:0 (17%), 18:0 (10%), 18:1 (5%), and 21:0 (48%). It is of some considerable interest that hair cuticle lipids are highly conserved, in marked contrast to the high interspecies variability in sebaceous gland lipids. Evidence that lipids are surface bound is inferred from data showing that increasing hair fiber diameter is associated with a decrease in total bound fatty acid. Thus, it is now well appreciated that hair fibers have a 3–30 nm coating of long-chain fatty acids bonded covalently to the protein membrane of the epicuticle. Recent technologic advances, e.g., in atomic force microscopy, have allowed exceptionally high-power views of the hair

fiber surface and how this is altered by changes in temperature, hydration, pH, lipid layer removers, topically applied cosmetic products, etc. Small amounts of cholesterol sulfate, cholesterol, and fatty alcohol are also associated with the F-layer, although the nature of bonding (e.g., via thioester linkages) is unclear [123].

Human hair is commonly grouped into just three main subtypes: Caucasian, Mongoloid Asian, and African. Differences between these groups are usually determined with respect to a range of parameters, including hair fiber diameter and its cross-sectional form, overall fiber shape, mechanical properties (see above), combability, shape, pigmentation and pigment distribution, chemical make-up, and moisture level [99]. For many of these parameters, Caucasian hair falls intermediate to the Asian and African extremes. Recently, a systematic examination of the protein structure of hairs from Asian, Caucasian, and African individuals revealed no differences by X-ray analysis in the structure of the hair keratin. Asian and Caucasian hair fibers are more cylindric than those of Africans, and it has been shown that "breaking stress" and "breaking extension" values are lower in African hair fibers than in Caucasians or Asians. These features also aid identification for hair fibers found in forensic and archeologic contexts. Despite these gross ethnic differences in the form of hair fibers, the chemistry of the hair keratin is remarkably similar throughout all humans.

24.5 Survival and Recovery of Hair from Different Depositional Environments

The robust properties of hair as an external feature of mammals have ensured that it may persist in numerous types of depositional environment postmortem [131]. However, if a body is simply allowed to undergo putrefactive change, then the skin will start to blister and the epithelium is readily shed, taking with it the hair (see above) [60]. In such cases, the hair may then be dispersed by a variety of means dependent on the depositional conditions. For example, hair collected from surface-deposited remains may be used by birds and small mammals as nesting material [11], and in aqueous environments, the movement of water, combined with putrefactive changes, may result in total loss of hair. Another significant transformation in moist/wet environments is the formation of adipocere, a function largely of biochemical changes to subcutaneous fat [36–39]. In circumstances where adipocere forms, the skin will be disrupted by a variety of changes that include volumetric expansion and again the hair is less likely to be retained.

Archeology has shown us, however, that hair and fibers may persist over extended timescales [16, 132]. Perhaps, the most recognizable conditions in which hair may survive are those extreme environmental conditions in the archeological record that have resulted in exceptional preservation of other soft tissues – conditions that are conducive to natural mummification [7]. The term mummification has traditionally been reserved for desiccated remains, which may be recovered from cold-dry as well as hot-dry environments and with forensic casework can include temperate climatic conditions where there has been air-flow, such as within cellars or attic spaces [6], or where individuals were emaciated [59]. However, well-preserved remains may also be recovered from frozen, saline, calcareous/limed deposits, including cave sites [8, 44] or acid peat conditions where the action of decay microorganisms is inhibited [135]. In fact, some of the oldest known hair samples are nonhuman and derived from permafrost sites, and because of their condition, usable genetic information may still be recovered from these samples despite their age [48, 49] and alteration [47, 50].

It should be remembered that much of our current understanding of human hair is based on work first undertaken for the benefit of wool production and sheep breeding [55, 93, 124]. As such, it is important not to ignore the fact that keratin fibers from other species have relevance in archeology also. Much can be learned from fibers and the uses to which they have been put, and a combination of textile, environmental, and genetic evidence offers us an insight into the agendas of sheep domestication [23] and the trade and exchange of goods/animals/raw materials [2, 43, 74, 94, 119]. Human hair has also been put to use in the production of hats, textiles, mats, and even string used as bindings [1, 22].

Within Western Europe and North America, although unusual instances of hair and textile fibers are known from cist burials [32] and midden deposits such as found at Deer Park Farms in Northern Ireland [129], most archeological hair samples from temperate climes are derived from more recent eighteenth and nineteenth

Fig. 24.2 Plaited hair recovered from a 19th century burial in West Yorkshire, UK

century burials (Figs. 24.2 and 24.3). These contexts are varied in their preservation, particularly when you consider that these remains may be derived from both deep (sometimes waterlogged) urban deposits as well as crypts, and that coffin construction varies from wooden single shell to triple-shell, lead-lined coffins [95] and iron caskets [88], each of which has a contribution to the condition of hair and other organics held within.

Fig. 24.3 The differential preservation of hair shown in-situ during the excavation of a 19th century burial in West Yorkshire, UK

24.6 Significance of Hair in Forensic Investigation

The value of hair and fibers have long been recognized both in relation to forensic examination [96] and human identification [131], and various properties of hair aid in this regard – the large number of hair follicles on the average scalp; the mosaic hair cycle in humans ensuring loss of large numbers of hair fibers each day (approx. 150) via natural shedding; the frictional properties of the hair cuticle that provide contact evidence and allow hair and fibers to persist on clothing [90, 122]; the morphological characteristics (diameter, pigmentation, cuticle, cortex, and medulla form), which offer both species and racial distinction. However, hair shaft comparisons on purely morphological grounds [87] are rare, generally requiring the support of other scientific tools.

Key developments in the application of DNA-based techniques have seen the validation of mtDNA from the hair shaft in 1995 [136, 137] and the use of the recovery of low-copy number (touch) DNA from the hair bulb in shed or forcibly pulled fibers [54]. More recent work has investigated the fate of mitochondria in the keratinizing hair shaft [71], and the future potential of RNA from hair has also been proposed [12]. However, it is clear that hair is not without its difficulties when it comes to genetic analyses [52, 102, 131]. In cases of serious assault and murder, new approaches to the collection of hair and fibers such as total fiber taping [26] will see further interest in the evidential value of hair.

Hair is of critical importance in offering a perspective on chronic usage when it comes to the ingestion of either toxic or controlled substances. As a consequence, there is now a keen interest in the value of incremental data for instances of suspicious death, both with cases of long-term substance abuse [67] or questioned administration of prescription drugs [45, 84] and alcohol use [89, 91].

As an excretory tissue, hair is a natural sink for toxic materials and, as a consequence, is used in biomonitoring, with the potential to chart occupational exposure to heavy metals [30, 62]. Laser ablation inductively coupled plasma mass spectrometry even offers the potential to provide measurements on single hairs [107].

Stable light isotope data can provide important lifeways information for individuals [24]. Incremental stable light isotope measurements from hair have been used to

provide intelligence on the potential origin and movement of unknown individuals, as in dismembered and/or decomposed victim remains - discriminating on the basis of oxygen and hydrogen isotopes [35, 41, 42, 76, 82, 85, 92]. The same principle also offers the potential for intelligence on living individuals in the case of recent migrants [15] or terror suspects. Radiocarbon dating of hair and other tissues relative to global atmospheric values generated by nuclear testing since the 1950s has the potential to offer dating evidence for postmortem remains [83].

Increasingly, hair can have a major significance in the investigation of wildlife crime, and in this regard, protein sequencing and isotope analysis can be seen as two novel and highly discriminating tools to augment DNA investigation [101]. Considerable progress has been made toward sequencing of keratins for the purposes of species identification [57, 58], with progress made toward establishing reference data [56, 105, 139]. In this regard, it is important to remember that keratotics also encompass feather, hoof, horn, claws, and tortoise shell [3, 13, 28, 29, 31, 106, 140].

Hair itself is a physical trap for natural (soil, pollen, diatoms, testate amoebae, etc.) [138] and anthropogenic information (explosives and gun shot residue (GSR) data) [72, 141] both because of frictional characteristics of the cuticle and the fact that fibers are naturally imbued with a range of secretions from the apocrine and sebaceous glands.

24.7 Biogenic Information from Archeological Hair

Several sources have already flagged the unique importance of information from hair and fibers in archeology [127] covering various themes, including identification of fibers [108], dietary information and physiology, DNA, and drug use.

In archeology, the information derived from stable light isotopes, particularly when viewed as incremental data from hair segments, can have a bearing on key agendas, including diet and seasonality, physiological status, mortality patterns, social and economic status, trade and exchange, and locational information. Various studies are highlighted elsewhere [127]; subsequent isotopic studies have examined hair from curated samples of Plains Indians [100], from ancient Kerma remains from the Nile valley [112], and from eighteenth/nineteenth century deposits [130] and bog bodies [135]. One of the greatest prospects lies with segmental analysis of hair [5, 125], revealing for instance the mortality patterns from hair of Inca remains [126].

Several studies have examined in more detail the use of hair to offer lifeways information, including the remains of three children from Volcán Llullaillaco, North West Argentina providing evidence of status change in the 15-year-old Llullaillaco Maiden [133] and the Kwaday Dan Ts'inchi glacier mummy from North West British Columbia, who was found 80 km from the sea and whose bulk hair and bone cholesterol isotopic values indicate a shift in diet to include more terrestrial foods in the year before death [98], as well as groups of individuals from Peru [69, 125, 126].

New directions offering further potential with stable light isotope analyses include the ability to measure isotopic variation directly along single fibers using laser-ablation techniques [103] and development of the potential to analyze single amino acids from hair correlating these directly with dietary intake [75].

Based on the discovery that mtDNA can survive in fibers recovered from certain depositional environments [46], genetic information from hair has been used to address enduring questions such as the familial relationships of eight paleo-Eskimo remains discovered in the 1970s at the site of Qilakitsoq in Western Greenland [51]. Of these eight individuals, the relatively noninvasive nature of this testing (requiring in some instances only a portion of a single fiber) opened up for the first time the possibility of testing the 6-month-old infant from this assemblage, and thereby returning an identity and kinship to these remains that could not be afforded by other means. Further studies on material from the Duckworth collection have provided new insights into the origins and historical geography of certain mtDNA lineages of the aboriginal inhabitants of the Malay Peninsula [97], and more recently, nuclear DNA has been recovered from the hair of Siberian mummies dating from the sixteenth to early nineteenth centuries [4].

A pioneer in the application of drugs data from hair and other tissues from archeological remains is the research conducted by Larry Cartmell and coworkers. They provided the first direct evidence for use of coca in antiquity [19, 20] and have since examined the use of alcohol and other evidence from both South American and Egyptian remains [21]. Recent studies have sought to broaden the perspective of potential

drug records preserved in ancient hair to encompass other less well studied hallucinogens [9, 86].

The significance of hair in many cultures persists even today, with rites and rituals associated with the cutting of hair at distinct ages and a perception that hair is linked to witchcraft. When excavated, the Inca child mummies found on the tops of mountains in the South Central Andes were often accompanied by bags (made of either textile or animal intestines) filled with cut hair. In the case of the children from Volcán Llullaillaco in NW Argentina, mtDNA combined with isotopic evidence proved that these cut hairs were derived from the children themselves [133].

Concentration of toxic elements in hair [14] must be considered in the context of likely postdepositional uptake [64] or exposure to contaminants within historic collections. This is especially important in the context of quantitative data for prehistoric exposure to potentially toxic substances such as arsenic [63, 65, 66, 68] or methylmercury, which if real can provide valuable comparative data for current-day exposures, of particular importance for indigenous groups, for example, who continue to rely upon local traditional food resources [34].

Despite much literary and artistic evidence for ancient hair styles, hair stylistic information only rarely survives with physical remains. Recent scientific developments, examining both inorganic and organic evidence, have probed particular features of stylistic data from hair. Of note are hair preparations including the use of lead [120] and the recovery of cinnabar from the remains a high status Moche female individual from Northern Peru known as the Lady of Cao [78]; Paris team hair products; and the evidence of a "hair gel" and Celtic tonsure from the hair of the iron age remains of Clonycavan man at the National Museum of Ireland [79].

24.8 Taphonomic Considerations for Hair After Death

The term *taphonomy* is derived originally from the paleontological literature [33], but has been adopted more recently in both archeology and forensic science [113]. It is concerned with those influences (natural or anthropogenic – physical, chemical, or biological) and the resulting tissue transformations that occur from the immediate postmortem period through to their recovery and beyond. Consequently, it provides a key framework for understanding not only the survivability of material that may be looked for, but also the variables that will influence this. These influences on the survivability and decomposition of hair have been summarized elsewhere [128].

The relevance of taphonomy has been expanded to understand how different influences from the depositional environment affect the reliability of biogenic information, given that they may be altered or compromised by biological or chemical processes [61] and the influx of contaminants [53]. Similarly, it helps us to recognize the significance of appropriate handling, processing, and storage procedures from the point of discovery to the protocols for analysis, safeguarding against the risks of further alteration or contamination, and offering a key step in being able to assess the likelihood of spurious data. Although it has been demonstrated that with appropriate steps contaminating DNA can be removed to reveal authentic DNA even in degraded samples [47, 49], the sample processing methods can permit the successful removal of contaminants from even some of the most difficult of samples [119].

Many have observed the physical impact of keratinolytic organisms on hair, which in the case of fungi produce characteristic "tunnels" that bury into the hair shaft [27]. The external lesion that results from the penetration of the outer cuticle manifests as an ovoid hole with eroded margins (Fig. 24.4). Once the fungal hyphae

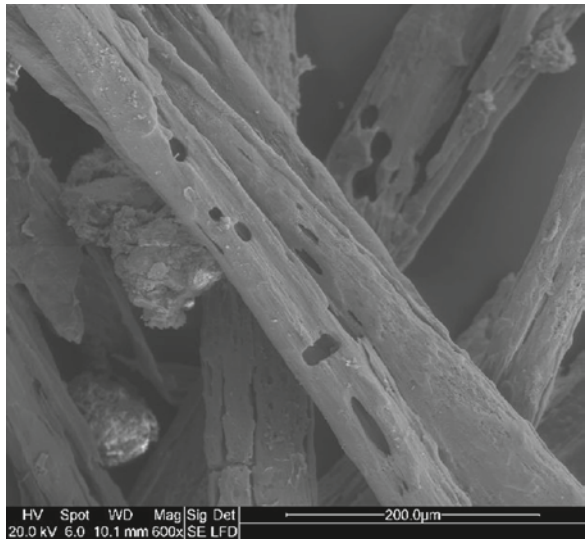

Fig. 24.4 Hair subject to fungal tunnelling by keratinolytic fungi

penetrate the cuticle, they can track laterally within the fiber, disrupting the cortex and medulla and affecting the different structures of the cortex in a predictable fashion [134]. The progressive destruction of the fiber, which ultimately results in the loss of keratin structures leaving melanin pigment granules and the remnants of cell wall structures, can be examined by means of a histological index [128]. These predictable changes can be correlated with the survivability of biomolecular information [47], although it is recognized that damage to degraded DNA templates may be highly specific in type, correlating with the geographic location and the taphonomic conditions of the depositional environment from which the remains are recovered [70].

It is important to recognize that, although there is a considerable interest in archeological remains, many such samples have languished in museum or private collections for many years, collections which in some instances may only have a partially documented history, raising questions of authenticity. This is exemplified by the varied origin of historic hair samples from different collections by means of mtDNA—samples that had all been attributed to Sir Isaac Newton [48].

Antiquarian interest, particularly during the nineteenth century, saw the assembling of numerous collections from many parts of globe, and these collections have generally only been subject to the scrutiny and protection offered by conservators and collections managers within recent decades. As such, hair samples from within these collections have often been subject to a variety of different insults from uncontrolled environmental conditions and exposure to both microbial and insect agents of decay; the indiscriminate use of biocides to try to limit infestations (including use of chemicals such as arsenic or nicotine); and to the unchecked habits of collectors and museum workers themselves in the vicinity of their collections (including smoking of tobacco and other products) [18, 81]. All such insults have made an impact on studies involving hair samples and, in some instances, have also spawned controversy, as with the findings reported by Balabanova and coworkers who claimed that nicotine, cannabis, and cocaine were present in samples of Egyptian mummy hair [10], now widely disputed [17]. This concern with the handling of hair and fibers is clearly recognized with modern forensic evidence and the collection and sampling of archeological fibers now overlaps with these ideals in terms of best practice.

24.9 Conclusions

Given the potential for hair to persist over both forensic and archeological timescales, it is hardly surprising that an expanding literature, highlighting the value of hair in these areas, now exists. It is now recognized that key properties of hair offer us the potential for unique data – the most significant being incremental hair growth, which enables segmental analysis to provide a diachronic picture that allows for subtle changes in the final months of an individual's life to be charted in great detail.

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