7.3. Hair Analysis

Learning Goals and Objectives

Hair and fiber information can provide valuable forensic information on the origin and history of the sample. In order to understand how hair analysis can be used, you will need to develop an understanding of:

- the chemical composition and structure of hair;
- how hair is formed and how it grows;
- how we can tell human hair from that of other animals;
- how we can tell where on the body a hair sample originated;
- how ethnicity information can be gotten from a hair sample;
- how information about the treatment of hair can be obtained;
- how hair can be used in toxicological studies;
- how diseases and abnormalities can be used to characterize hair samples;
- how hair samples are collected and analyzed;

Introduction

In the early biological development of a person, both the skin, with its friction ridges, and hair form from the ectoderm, or outermost, layer. As such, hair and skin not only share a strong biological connection, with hair considered as a derivative of our skin, but also more simply, both of these tissues are found primarily on the outside of an organism. Hair and skin are, therefore, the components of our bodies that directly face the environment and can very easily leave lasting and identifying forensic evidence. Because of the similarity of hair and fibers in their form and forensic function, we will consider them together in this section, beginning with a consideration of hair.

Hair and fiber samples are among the most durable of all biological materials and retain much of their forensic value for many, many years. While most biological tissues are usually quickly destroyed after death, hair samples have been known to persist virtually unchanged for thousands of years. These samples can provide both structural and chemical clues as to both their individual origin and the underlying biochemistry that formed them. Similarly, durable fibers, both natural and man-made, are found throughout our society in cloth and other items that can provide useful information about their origin, composition, form, and use.

Hair and Fur. Hair is a complex appendage that grows from a follicle in the skin of only mammals and is a derivative of the epidermis of the skin. One of its main purposes is to help regulate the body temperature of an organism by either trapping or releasing warm air near the skin’s surface. The protective function of hair and its exposure to extreme conditions requires it to be strong and durable.

Hair has enormous diversity of form – both between two different species of organisms and from individual person to person. Traditionally, hair from non-human mammals is referred to as fur rather than hair, but the structures are typically very much the same.
Composition of Hair: Hair is composed of about 80 to 90% protein, mostly keratin and melanin, and between 8 to 15% water, with the remainder mostly as lipids. Keratin is a tough, durable, fibrous protein composed of long chains of amino acids typically found as a structural component of hair, nails, horns and claws. Melanin, however, is a pigment polymer derived mostly from the amino acid called tyrosine that imparts the color to a hair sample. Generally, the darker the hair, the more melanin it contains. There are, however, several types of melanin commonly found in hair. The dark pigment called eumelanin colors black and brown hair while the pigment called pheomelanin is the main coloration chemical found in red hair. Blonde hair simply has lower amounts of melanin overall while gray hair typically lacks melanin completely. All hair samples have very similar chemical compositions which limits the use of a chemical analysis in the individualization of hair sample as coming from a particular person.

Hair Structure: Hair grows from a hair follicle, a tiny hole in the skin, located within the upper layers of the skin, as shown in Figure 7.3.1, and consists of a root, shaft and tip. The hair shaft grows from the base of the follicle in an area known as the dermal papilla to form a rapidly elongating hair bulb. The growing hair root is fed by its own blood supply with new cells pushing the previously formed cells upward. When the hair shaft grows, the follicle deepens into the skin layers while the shaft grows out of the follicle. As the shaft elongates, the hair begins to form several layers as cells die (Fig 7.3.2). The portion of the hair shaft that extends beyond the surface of the skin is, therefore, composed mostly of dead keratinized (cornified) material. The only living portion of a hair is, therefore, the portion that is still in the follicle.

It is important to note that since the cells in the shaft are dead and keratinized, it is almost never possible to extract nuclear DNA from the hair shaft. Mitochondrial DNA, however, can often be found in the shaft for analysis and is stable for long periods of time. It is possible to collect nuclear DNA from a hair sample if the sample contains some of the living cells from either the hair root or from the follicle itself. This is common if a hair has been forceably removed and some of the tissue from the follicle is pulled out with the hair fiber.

Figure 7.3.1. Structure of a hair follicle

Figure 7.3.2. Structure of the hair (L, www.pg.com/science/haircare/hair_rwh_13.htm) and colored scanning electron micrograph (SEM) of hair shafts growing from the surface of human skin (R, www.sciencemag.org, Image P720/255).
Copernican Hair?

Nicolaus Copernicus (1473-1543) was a Renaissance church canon and astronomer who changed forever our perception of the Universe and our place in it. Prior to his work, the prevailing attitude was that the Earth was the center of the Universe and everything else revolved around it. Copernicus said, however, that the Sun was instead the center and that the earth and all planets revolved around it. Historians often point to his seminal work as the beginning of the scientific revolution and modern science. But until recently, the remains of this most influential scientist were missing.

When he was buried in Frombork Cathedral, Poland on May 24, 1543 beneath the altar floor, the place of his internment was not marked and ultimately lost to history. In 2005, however, a skull and some remains were unearthed after a five year intensive search from Cathedral that archeologists thought might be those of Copernicus. Scientists were able to extract some mtDNA from one of the teeth in the skull and a femur bone but the problem was what to compare it with?

As it turns out, the key evidence came from an unlikely place. In the Stoefler Almanach Copernicus library in Uppsala, Sweden, two hairs were amazingly found in 16th century astronomy reference book that had belonged to the great astronomer. Mitochondrial DNA was extracted from the hair samples were found to match well with the mtDNA extracted from the bone fragments, provide very strong evidence that the skeletal remains found in the cathedral is that of Copernicus.

Using facial reconstruction techniques on the skull (inset picture, see chapter on forensic anthropology) scientists have been able to reconstruct Copernicus’ face (inset, www.crystalinks.com/copernicus.html) that corresponds remarkably well with existing portraits of his. On May 25, 2010, his remains were reburied with full honors beneath the altar where they were found.

The follicle has associated with it sebaceous glands that produce sebum, an oily material that protects, lubricates, waterproofs, and helps to inhibit the growth of microorganisms on the hair. The follicle is also attached to a muscle (arrector pili muscle) that serves to elevate and lower the hair fiber in response to environmental conditions. Contraction of the erector pili muscles also produces what are commonly known as “goosebumps”.

Figure 7.3.3. (Top to Bottom): coronal, spinous, and imbricate[1](http://commons.wikimedia.org/wiki/File:Haarstrukturen_im_Vergleich.png) (On right, top to bottom) are examples of coronal (bat), spinous (mink), and imbricate (human) patterns[2](http://www.chem.sc.edu/analytical/chem107/lab4_032205.pdf).
Thus, when it’s cold outside, the erector muscles contract to raise the hair shaft to trap a layer of warm air next to the skin to help keep us warm and conserve body heat.

Each mature hair fiber is typically made up of three components: the cuticle, cortex, and the medulla. The outermost translucent layer of a hair shaft is called the cuticle which appears similar to the shingles on a roof or the scales on a snake skin, with the exposed portion of the “scale” aimed towards the tip of the shaft (Figures 7.3.3 and 7.3.4). You can sometimes feel this directionality of the cuticle scales by first running your pinched fingers moving along a hair shaft from your head toward the end of the hair and comparing it with running your fingers in the opposite direction from the tip. Often feels rougher when moving from the tip towards the scalp since this is moving against the “grain” of the cuticle scales towards your head. This relatively thin layer, usually just six to ten cells thick, protects the hair by forming a waterproof and rather impervious layer that coats and protects the entire shaft.

The pattern formed by the overlapping cuticle cells is very distinctive and can be easily used to determine the species of animal that produced the hairs, Figure 7.3.4. The three general types of scale patterns most commonly observed, shown in Figure 7.3.3, are the coronal (“crown-like”), spinous (“petal-like”), and imbricate (“shingle-like”) patterns. The coronal pattern, common in small rodents, appears similar to an arrangement of stacked “crowns” or circular bands. The spinous pattern, found in the hairs of cats and mink, appear like triangular “petals” that often project away from the shaft of the hair. The imbricate pattern, found in human hair, appears as flattened scales.

Since the cuticle is the part of the hair directly exposed to the environment, it is susceptible to damage by sunlight, wear, and the way that people treat and style their hair. For example, dyeing, drying, and styling hair can permanently damage this layer.
If we could peel back the outer cuticle layer, as shown in Figure 7.3.5, the underlying cortex layer would be exposed. The cortex makes up most of the bulk of the hair shaft and gives the hair its characteristic elasticity, stretching up to 30% of its length. The cortex is primarily made up of long, twisted and coiled protein fibrils, like a curly telephone cord, that easily bend when the long molecules slide past one another (Figure 7.3.5). When stretched, these molecules can uncoil like a spring and when released the molecule can reform its original coiled structure, giving hair its observed elasticity. Pigment molecules, giving the hair its color, are also largely found in the cortex layer.

Occasionally, small structures are observed within the cortex of a hair fiber, providing additional comparative information. For example, air bubbles, known as cortical fusi, pigment bodies, small area of pigment concentration, and ovoid bodies, larger pigment-containing structures with regular boundaries, are observed. Ovoid bodies, often found in dog hair but only occasionally in human hairs, are shown in Figure 7.3.6.

Figure 7.3.5. Scanning electron micrograph showing a human hair with the cuticle folded back to reveal the underlying cortex layer (http://piclib.nhm.ac.uk/piclib/www/image.php?search=hair&getprev=49994, Image reference: 4650).

Figure 7.3.6. Ovoid bodies, oval pigment-containing bodies, in dog hair (http://www.chem.sc.edu/analytical/chem107/lab4_032705.pdf).

Figure 7.3.7. Patterns observed in hair medulla (http://atcg.bio.cmich.edu/Medulla.jpg).
The third and innermost component of hair is the medulla. This part of the hair is characterized by either very spongy cells or no cells at all, forming a canal-like structure in the center of the shaft, often called the medullary canal. Melanin can also be found in this layer, contributing to the color of the hair. The medulla in human hair can form a continuous canal, be interrupted by areas without a medulla, or be missing a medulla altogether, Figure 7.4.7. The medulla pattern for some animals can be rather complex showing ladder-like or lattice-like patterns.

The ratio of the diameter of the shaft to the diameter of the medulla can be defined as the medullary index (MI) that can be used to help distinguish human hair from that of other animals. In many animals, the MI is greater than 0.5 while in humans it is typically found to be less than 0.3.

Hair varies greatly depending upon its location on the body. When we are fetuses, our entire bodies are covered with very fine colorless hair, called Lanugo. During early childhood, however, this lanugo hair is lost and the majority of our bodies are covered with fine short hairs, called Vellus hair or sometimes referred to as "peach fuzz". During puberty, humans develop longer, thicker, colored hair on various parts of the body, besides the scalp and eyebrows, called terminal hair, that forms part of our secondary sex characteristics. Terminal hair includes hair found on our scalps, in armpits, on legs, chest hair and elsewhere.

Usually, a single hair follicle produces only type of hair but sometimes a follicle can change to produce a different type of hair. For example, until puberty, the facial follicles on a male produce only fine vellus hair. During puberty, these follicles change to produce a characteristic male beard made up of thicker, longer terminal hair. Similarly, follicles on the scalp usually produce only terminal hair but in some instances (androgenetic alopecia) the follicle can change to produce short, thin, lightly colored hair.

Most animal hairs are divided into three basic types: guard hairs (from the outer coat for protection), fur (from the inner coat for insulation and temperature regulation), and tactile hairs (for sensing, such as whiskers). Human hair, however, is not so well differentiated, resembling animal fur most closely.

The overall shape and length of a human hair can give information about where on the body it originated, such as the scalp, face, public area or elsewhere on the body. For example, scalp hair is usually long with cut or split tips and a relatively narrow medulla, while pubic hairs are typically short, with a tapered or rounded tip, and contain a relatively broad medulla. Because of the variation of hair structures, even on one individual person, it is often necessary to collect many hair samples in order to get a representative sample. This also makes it very difficult to determine if a particular hair fiber originated from a particular person.

**How Hair Grows:** Hair growth occurs in a cycle composed of three main stages: the anagen, catagen, and telogen phases (Figure 7.3.8). The lengths of these cycles are genetically programmed and can vary...
greatly from person to person and from place to place on the body. For example, the entire cycle can take 4-5 years for scalp hair while the cycle is completed in 3-4 months for eyebrow hair. In humans, these stages do not occur at the same time for all of the follicles – each follicle has its own timetable. This, however, is not true for other animals in which the phases are timed to occur simultaneously accompanied by the shedding of hair, for example when a rabbit changes its hair from the darker summer coat to the white winter coat of hair (Figure 7.3.9).

The **anagen** phase is the active growth time of the cycle. During this phase, the cells at the base of the follicle rapidly divide and push “upward” to produce the new hair shaft. The cells in the base of the growing hair bulb are the second fastest growing cells in the body (right after the blood-producing cells of the bone marrow). In humans, this phase can last between several moths and many years. The anagen phase on scalp hair can last up to five years while for hairs of the eyebrows, the anagen phase might last only several months. This is why hair on the scalp is much longer than arm or eyebrow hair.

Generally, a hair fiber grows about $\frac{1}{2}$ inch per month (0.3 – 0.4 mm/day). Thus, the tip of an individual hair a foot long began within the follicle about two years earlier.

The **catagen** phase can best be though of as a transitional phase, and usually accounts for 3-5% of all body hairs. It is during the catagen that hair growth stops and the portion of the follicle surrounding the hair root shrinks considerably, by about two-thirds, through cell death of the follicle and attaches to the root, forming a “club” shaped end (Figure 7.3.10). This process results in major destruction of the lower part of the hair follicle, including the cells that produce the keratin and melanin that form the hair. Usually the catagenic phase last several weeks for all types of hair.

The final phase, the **telogen** phase, is a resting period for the follicle. In this phase, the club root has completely formed. The bulb on the dead hair helps to keep the hair in the follicle tube but the hair can readily fall out since it’s no longer strongly “connected” to the follicle. This phase can last from a few months to years, depending upon it’s location on the body and usually about 10-15% of all hairs are in the telogen phase at any given time. On average, a typical person has between 100,000 and 150,000 hairs on their heads and lose between 50 and 100 hairs every day due to the normal hair growth cycle.

A fourth phase, the **exogen** phase, is sometime considered, although it is associated with the hair fiber itself rather than the follicle and simply has to do with the loss of the hair shaft from the follicle. This process is poorly understood, however, but it is believed to be important in the timing of the restart of the new anagen phase of hair growth for the follicle.

These phases typically continue over the entire lifespan of a person. Sometimes, however, this pattern is either interrupted or the follicle destroyed by medications, radiation, genetics or other causes.
Sex and Ethnic Differences in Hair Structure: Anthropologists broadly divide the peoples of the world into three major categories: Asian (Mongoloid), Caucasian (Caucasoid), or African (Negroid). This will be described in more detail in the chapter on forensic anthropology, but occasionally some information regarding ethnicity can be gained by examining hair samples, as shown in Figure 7.3.11.

Asian hair tends to be round in cross-section with a greater diameter than other types, although generally less dense than hair of other ethnicities. This tends to lead to hair that is thicker, more straight and more difficult to curl than hair of other origins. Caucasian hair tends to be oval in cross-section and more physically durable to bending and stretching than hair of other ethnic types. It is also often relatively straight but flexible so as to form loose curls easily. African hair tends to be oval to relatively flat (“ribbon-like”) in cross-section allowing it to form tight curls readily while remaining very strong across the width of the fiber. Additionally, the fiber tends to vary greatly in its thickness and twist along the length of the shaft in contrast to other ethnicities.

It is typically very difficult to determine the age or sex of an individual from hair samples. It is sometimes possible, although relatively rarely done, to recover follicle cells from the root of forcibly removed hairs. These cells can be stained and examined under the microscope to reveal specific sex-related characteristics, such as the Barr body for females or a Y body for males (shown in Figure 7.3.12).

Hair Treatment: Hair has important cultural significance beyond its necessary biological functions. People style, condition, shampoo, color, cut and modify their hair in innumerable ways. Today, over 75% of women in
the United States color their hair, with red being the most popular choice. Each process we do to our hair can be “recorded” in the fibers, and this record can help to individualize a fiber by marking the history of its treatment. These modification can, therefore, be used to advantage to help identify a particular hair and to learn something about its past.

The color of hair can be readily altered through the use of dyes and rinses. To permanently change the color of hair, however, pigment molecules must pass through the outer cuticle layer and be deposited within the cortex. When pigment molecules adsorb only on the outer cuticle layer, the color may be vibrant but it is also readily removed by simple washing. This is the case with temporary coloration methods such as certain rinses, sprays and foams.

For a more permanent coloration, the pigment molecules must first penetrate the tough outer cuticle layer. This requires an alternation of the cuticle layer to make it permeable to the pigments since the cuticle is designed to protect the cortex from the environment and to resist the movement of pigment into the hair. In order for permanent coloration to occur, the cuticle must, therefore, be chemically treated to open up its scale-like structure – requiring relatively harsh chemical steps. Chemically, this process usually employs an oxidizing agent, an alkaline (basic) agent, and a conditioner beside the dye. An oxidizing agent is something that removes electrons from a molecule, such as hydrogen peroxide (H₂O₂). An alkaline agent is a basic chemical, such as ammonia (NH₃), that can react with acids. In the permanent dying process, ammonia is often used to open up the cuticle, thereby allowing the dye to penetrate into the cortex, and to catalyze coloration reactions in the cortex. This process also breaks the majority of the sulfur-sulfur bonds holding the inner keratin strands of the hair together, releasing the characteristic odor of sulfur and causing the hair to “relax”. The hydrogen peroxide is used to remove the pre-existing natural color of the hair and facilitate the reformation of the sulfur-sulfur linkages. Finally, a conditioner is usually used to close up the scale-like structure of the cuticle after the process is

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**Can Your Hair Turn White Overnight with Fright?**

There are plenty of stories throughout history where someone, faced with extreme fear or a severely traumatic experience, reportedly has their hair turn completely white overnight. Legend has it that the hair of some famous people, such as Sir Thomas More (1535) Henry of Navarre, later Henry IV of France (1572), and Marie Antoinette (1793), went white overnight when faced with imminent death.

These tales, however, do not have a basis in current scientific research. White hair arises from fibers that do not contain any melanin pigments. When someone goes “grey”, it simply means that they have a mixture of colored and uncolored (white) hair. Since the amount of pigment in a hair fiber is fixed at the time it forms within the follicle, even if a hair follicle stopped producing melanin overnight, the hair fiber beyond the follicle would still remain pigmented since the hair is dead. Thus, if all the follicles on a person’s head stopped producing melanin at once, the hair would still be largely pigmented. Additionally, there is no research evidence that shows that stress can significantly cause hair to stop producing melanin, or go white – it’s largely determined either by a person’s genetics or access to bleach.

There is, however, a fairly rare autoimmune disease (a disease in which your body’s immune system turns against itself) called *alopecia areata* in which hair follicles are very rapidly destroyed, even over a few days. There is a particularly rare form of this disease, however, that seems to attack only the pigmented hair follicles, leaving a person with only unpigmented or white hair. Assuming that all the pigmented hair fell out immediately, the remaining white hair would remain giving the appearance of a rapid transformation from colored or grey hair to white hair – but this certainly would not happen overnight.
completed. Often, however, this harsh chemical process results in a damaged cuticle layer that can be useful in forensic investigations by telling a story about recent treatment of the hair, as seen in Figure 7.3.13.

It is occasionally possible to determine a rough timeline of when the dying process may have occurred by observing cuticle damage that is found some distance along the fiber but not at the base of the shaft. By noting the distance from the base of the fiber to the beginning of the damaged area, a rough indication of how long ago the dye process occurred can be estimated given the average rate of growth of the hair and knowing that hair grows only from its root. Additionally, observing a sharp color change near the root end of the hair fiber, with color that is dense and relatively even throughout the cortex, is evidence that the hair has been dyed.

Hair can also be changed to be curled, waved, or straightened through a process often called permanent curling or “perming”. About one-quarter of the keratin in hair, the major protein component that gives hair its characteristic shape, is composed of cysteine, a sulfur-containing amino acid. The keratin chains in hair are linked together through interconnecting the sulfur atoms, forming disulfide bonds. These linkages largely fix the shape of the strand in much the same way that the rungs of a ladder hold the two vertical poles together to give rigidity and structure, as shown in Figure 7.3.14. When hair is chemically “perm ed”, a chemical (such as sodium thioglycolate) is first used to break about 30% of the disulfide bonds between the keratin strands. When the hair is placed in the desired shape, the keratin strands are now free to slide past each other and assume the new shape of the form it is placed in. Finally, another chemical, such as hydrogen peroxide or a similar oxidizing agent, is applied to reform disulfide linkages between adjacent cysteine units. In this final step, however, there is now a new pattern of pairing between adjacent cysteines, thereby permanently locking into place the keratin strands into a new shape. This would be something like “unzipping” the rungs of a ladder, moving the two poles to a new orientation relative to each other, and then “re-zipping the rungs together to “fix” the new arrangement of the poles.

The curl is permanent only on existing portion of hair when the permanent was done and, as new hair grows or the old hair is cut, the effect of

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Figure 7.3.14. Disulfide bond breakage and reforming during the “perming” process to hair (unknown).

Figure 7.3.15. Hair fiber that has not been washed in several days shown dead epithelial skin cells adhering to the hair shaft (http://www.pantene.com/haircare/hair_twh_12.htm)
People also very commonly clean and style their hair through regular cleaning and the application of hair products. Several forensically interesting pieces of information can be gained by considering the cleaning and styling of hair fibers. As shown in Figure 7.3.15, information about any recent washing can be revealed microscopically. Additionally, chemical analysis of the surface or rinsing of the fiber can also show residues of particular types of rinses and chemical treatments (see the section on chemical analysis).

Cutting hair, either to maintain a desired hairstyle, or through accident, injury, or assault can also be used to provide important information on the history of a hair sample. Examples of a few of this type of information from hair fibers can be seen in Figure 7.3.16.

**Figure 7.3.17.** The effect of zinc deficiency on hair growth. The picture of left shows a child with a zinc deficiency with thin and sparse hair. After treatment with a zinc supplement, his hair growth is more normal (www.pgbeautygroomingscience.com/the-hair-growth-cycle.html).
Abnormalities in hair structure can also help in characterizing a hair sample. One example of many is the striking *pili annulati* hair abnormality which comes from an unusual process in forming the keratin of the hair fiber. This condition results in a cortex that is not solid but rather contains air pockets in a regular pattern along the length of the fiber. These air pockets effectively reflect the light so that the hair appears to be banded (Figure 7.3.18). This distinctive condition is genetic in some circumstances while the cause is unknown in other instances.

Occasionally, it is possible to detect hair infestations, such as mites (arachnids – related to spiders, not insects), lice (insects), and others, as shown in Figure 7.3.19. These can help provide both a connection with a known person and information about the history of the sample.

**Hair Toxicology:** When hair grows within a follicle, certain biochemical conditions existing in a body can be recorded directly within a growing hair shaft. Chemicals can be transferred from a person’s bloodstream to the follicle and then deposited in the growing hair, as illustrated in Figure 7.3.20. As the shaft continues to grow, the chemical record contained in the living portion of the hair is pushed out of the follicle and becomes a permanent snapshot of what was going on in a person’s biochemistry at the time the fiber was formed. Once the newly formed portion of the hair shaft leaves the follicle and dies, this record can last for a very long time. For example, certain drugs or their metabolites (chemicals that the body transforms the drug into), such as cocaine, heroin, amphetamines, and others, are deposited from a person’s bloodstream to the growing hair fiber.

Some drugs, particularly those that are bases, bind tightly to the melanin since melanin is an acid. Therefore, the darker the hair, generally the more melanin and the more drug binding found. Neutral drugs also tend to enter the hair more easily. Some drugs get into the hair through the sebum (sweat), especially when the cuticle is damaged. Of concern, however, is that chemicals from the surrounding environment (e.g., dirt, smoke, etc.) can also make their way into the hair and affect any later chemical analysis to detect drugs.

Since hair grows at a rate of about ½ inch per month, a rough timeline of drug or poison intake events can be estimated by chemically analyzing different portions of the hair along the length of its shaft. This form of analysis has become an important part...
of drug surveillance for people on parole, checking to see if a patient has been complying with a therapeutic drug therapy, or checking the reliability of a person’s statement regarding drug use. Beside serving of a record of drug use, this toxicological information can also aid in determining if two fibers have a common source – for example, one found at a crime scene and one taken from a victim.

As mentioned before, analysis of hair fibers can provide record a person’s exposure to environmental toxins in the air, water, food or elsewhere. Hair can also serve as a strong piece of evidence showing a person’s long-term use of alcohol. When alcohol is consumed, the body produces fatty acid ethyl esters (FAEE), ethyl glucuronide (EtG), and ethylsulfate (EtS) (Figure 7.3.21). While alcohol is not deposited in hair, these three metabolites of alcohol (ethanol) are permanently deposited in growing hair fibers, making a lasting record of alcohol use – even years long.

There are a number of both important advantages and challenges in considering toxicology issues in hair samples. Hair is usually a readily available, non-invasive, inexpensive, and long-lasting medium for analysis. In addition, chemical analyses have been developed for trace levels of compounds found within hair fibers. But hair analysis also has some significant difficulties. For example, darker and coarser hair fibers retain drug information longer and better than lighter and finer hair. This may lead to a different drug use profile determined from hair for two people with identical usages. False positives may also present significant problems, such as in the determination of alcohol abuse through EtG analysis. For example, in a recent study, it was surprisingly shown that a false positive can come from a person using an alcohol-containing hand sanitizer before the analysis. There is also problems in establishing a relationship between the amount of a drug found in a hair sample with what was in a person’s blood system. Other problems currently being addressed include: (1) use of hair from different places on the body, (2) ethnic differences in drug absorption and retention in hair, and (3) the effect of cosmetics. Nonetheless, the use of hair analysis for drug and toxin exposure is increasing rapidly and forms an important forensic tool.

**The End of an Emperor: Telltale Hair?**

Napoleon Bonaparte (1769-1821) is one of the most studied, despised, and revered of all people in history, with tens of thousands of books published on his life and exploits, with thousands of new titles appearing every year. He is certainly a man of intrigue and mystery but one of the greatest mysteries regarding this enigmatic man is the cause and manner of his death.

After Napoleon lost the Battle of Waterloo in 1815 and later surrendered to the British, he was exiled to the remote tropical island of St. Helena in the South Atlantic, still one of the most isolated places on Earth. He and his retinue of about 20 friends and associates lived for six year on the island, under the close watch of the British commander, before his death in 1821. At the time of his death, an autopsy was performed by British surgeons and the cause of death was determined to be a perforated (“bleeding”) stomach ulcer that had become cancerous. But today, nearly two hundred years later, controversy still remains surrounding his death.

During his exile, Napoleon often thought of escape and his relations with the British...

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*Figure 7.3.21. Structure of ethyl Glucuronide and ethyl sulfate.*
commander on St. Helena, Sir Hudson Lowe, were very bad, indeed. Lowe deeply distrusted Napoleon and had sentries posted constantly to follow Napoleon’s every movement. Napoleon, in turn, ultimately retreated to his home and grounds, Longwood House, and did everything possible to remain out of the sight of his sentries – he even had sunken walkways dug on the grounds to be able to walk outside without being seen by the sentries.

During his exile, Napoleon often wrote and said that he was being “murdered by the British Oligarchy”. His relatively rapid decline, along with the type of illness and symptoms he reported, has prompted speculation ever since that he was murdered and theories have abounded about who and why he was murdered. But new insights have come from, of all places, locks of Napoleon’s hair.

One theory of his death is that he was poisoned by arsenic – a well known 19th century poison. It was noticed that some of the symptoms of Napoleon’s demise closely resembled arsenic poisoning. But how to prove this – Napoleon’s body, removed from St. Helena in 1841 to a crypt in Paris, is not available for tissue analysis to look for arsenic? As it turns out, something almost as good is available – napoleon’s hair.

As part of an old custom, Napoleon bequeathed locks of his hair to his friends and family upon his death. Since hair provides a long-lasting record of toxins in the body at the time it is growing, analysis of his hair sample should show high levels of arsenic if this was indeed the case of his death. A bona fide Bonaparte hair sample was ultimately found and the arsenic analysis was performed. The analysis showed that there were indeed higher than normal arsenic levels in the former Emperor’s hair. But was he poisoned – some say yes while other theories have also been proposed to account for the arsenic levels.

In 1980, Dr. David Jones proposed that Napoleon was actually suffering from Gosio’s disease, a chronic arsenic poisoning from exposure to a common 19th century pigment – Scheele’s or Paris green. Scheele’s green contains copper arsenite that, under certain circumstances of high humidity and mold, gives off arsine gas. Almost miraculously, Dr. Jones found what is believed to be an actual piece of Napoleon’s wallpaper from Longwood House (inset – compare with the painting of Napoleon’s deathbed that shows the star pattern on the walls) that clearly had green pigment and chemical analysis showed that it contained definitively arsenic. But was it the cause of death? And why was Napoleon the only one affected.

As it turns out, others in Napoleon’s party complained of illnesses and the “bad air” at Longwood, including the death of his butler. But for a normally healthy person, the level of arsenic might not have been enough to cause severe illness. But to someone already in a compromised health state, such as Napoleon with a problematic ulcer, the added effect of the arsenic might have been
enough to be a significant contributing cause of death.

So, what did cause Napoleon’s death – at this point the evidence is not fully conclusive and we await more information. What do you think?

Hair Comparison and Identification: Probably the most important aspect of the examination of a hair sample is the observed microscopic structure of the medulla and cuticle of the sample. An individual hair fiber, however, cannot be individualized through its chemical composition or even usually from its structural features. The shaft of a mature human hair does not contain nuclear DNA so that only mitochondrial DNA analysis is possible for such samples. Often, however, tissue from the follicle may remain at the root of a hair sample, such as fibers forcibly removed from the scalp, so that a nuclear DNA analysis might be possible. Apart from DNA analyses, however, significant error rates are associated with the microscopic comparison of two hair samples. When comparing these samples, the color, length, and diameter of the hair fiber is particularly important.

7.3.2. Nails. Fingernails and toenails are, like hair, considered to be an appendage of the skin and are closely chemically related to the claws, hooves, and horns found in other animals. Like hair, nails are made up of the durable protein keratin. The importance of nails in forensic cases usually arises in assault or other violent cases in which pieces of an attacker’s or victim’s fingernail become lodged in the others clothing or skin. Finding and analyzing the nail can be an important piece of evidence.

Nails primarily serve to protect the very sensitive ends of our fingers and toes and actually increase the sensitivity of the fingers and toes. The tips of our fingers and toes are among the most sensitive portions of our bodies, through which we sense a great deal of information regarding the shape of the world.

Fingernail Growth. Like hair, the majority of nails are dead keratinized material. The only living portion is the end of the nail is the nail root, or germinal matrix, that extends under the skin opposite to the end of the nail and is where the nerve, blood supply, and lymph vessels are found (Figure 7.2.22). The nail grows continuously from the root as long as it is healthy and is nourished, growing an average of 0.5 to 1.2 mm per week. Fingernail actually grow much faster than toenails – typically taking about 6 months to completely regrow a new fingernail while it make take up to two years to fully regrow a toe nail.

Do Fingernails Continue to Grow After Death?

Many people believe that fingernails continue to grow after death and bodies exhumed after death appear to have much longer nails than expected. It turns out the this is actually an illusion based upon our normal “living” expectations.

The growth of the nails does indeed stop at death. After death, however, the tissue surround the nails shrinks and dehydrates, making it appear that the fingernails are longer. Since we are used to seeing fingernails grow and fingers remain the same size in life, we interpret what we see after death similarly – we think that the finger tissue remains the same size when it actually shrinks.
As new nail cells are produced, they are pushed out of the root area as white, opaque round cells. These newly formed white cells are visible near the root of the nail as a crescent shaped base of the nail called the lunula (“small moon”). The lunula appears largest on the thumb and gets smaller toward the little finger where it is often not visible at all. As the cells are pushed further away from the root area, they are flattened, compacted and ultimately die and turn translucent such that the pink blood capillary bed lying beneath the nail becomes visible. The nail plate, the actual nail itself, rides on the nail bed as it is pushed away from the root. At the sides of the nail is the cuticle, or eponychium, formed from the flap of skin the folds over the nail and form a waterproof seal with the nail.

The shape and structures of nails can tell us things about the health of a person. Nails that are colored, spotted, brittle, or grooved may indicate an underlying disease process in the person before other symptoms may appear. For example, pitting may indicate Psoriasis, white nails may indicate hepatic failure (liver), or blue coloration may suggest circulatory problems.

**Forensic Nails Use.**

Fingernails can be used forensically in a number of ways. In one case, a broken fingernail was found in the clothing of a suspect. This fingernail was matched with a broken fingernail on the victim, both in lengthwise striations and in the irregular tearing of the broken nail from the victim's nail plate. Work by Prof. Herbert MacDonell has shown that the striation in fingernails do not change over a person’s lifetime and are

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**A Very Cold Case: An Arctic Mystery.**

In 1871, Capt. Charles Hall led a congressionally backed expedition in the ship Polaris in search of the north pole. When expedition came with 500 miles of the pole in the late fall, Capt. Hall decided to set anchor and winter aboard the Polaris, much to the distress and outrage of several of the crew members. One day in late October, after drinking a cup of coffee at anchor, Capt. Hall be came quite ill and thought he had been poisoned. He died in early November before help could be arranged. He was buried in Greenland and a later medical examination found that he had died of natural causes.

The case rested here until 1968, however, when Hall’s body was located, exhumed, and an autopsy performed on site. Hair and fingernail samples were also taken for later chemical analysis. A neutron activation analysis (see the chapter on chemical analysis) was done on these samples and high levels of arsenic were found. The problem was, however, that the surrounding soil in Greenland was also found to be high in arsenic. But quite importantly, it was found that Halls nails and hair showed that he had received a large dose of arsenic about two weeks before his death and that arsenic levels were low elsewhere in the samples. This differential location of the arsenic in the nails strongly suggests that he was poisoned since if the arsenic came from the Greenland soil, a uniform distribution of arsenic in the entire sample would be expected rather than what was found.

Given the high arsenic levels in Hall’s nails in some places and not others, coupled with the symptoms that he reported before his death, it suggests that homicide should be the true manner of his death. There remains, however, little evidence to tie one particular person with this crime.
similar to a unique “barcode” for a person’s nails.

Fingernails often are found with tissue fragments attached to them when forceable removed that yields viable DNA samples. This has been successfully used in many cases and this evidence has led to numerous convictions. Additionally, like hair, fingernails can “record” biochemical information in their composition. There are reported cases of using nails to show the presence of toxins, such as arsenic, that was non-uniform along the length of the nail – suggesting that arsenic was applied at specific times to the victim.