7.2. Fingerprints

Learning Goals and Objectives

Fingerprints have been used for centuries as a unique mark of a particular person. We now recognize that each person has a set of ridges on their fingers that sets them apart from all others and, therefore, allows their fingerprints to be used to potentially identify their involvement in crimes. In order to understand how fingerprints are used, you will need to develop an understanding of:

- the origins and development of fingerprints as unique personal identifiers;
- the biological formation of “friction” ridges and their structures and features;
- the main patterns of fingerprints: loops, whorls and arches;
- the identification and use of minutiae and other fine features for identification;
- the meaning of visible, latent and plastic fingerprints;
- the methods for visualizing, lifting, preserving, and comparing latent fingerprints;
- the development of IAFIS and similar systems;
- The use of other biological structures for identification (e.g., lips, ears, skin);

Background and Introduction

The use of fingerprints for personal identification has truly been around, in one form or another, for millennia. In the ancient world, fingerprints were regularly used in China, Japan, Babylon, and other places to certify business transactions and as a personal sign for important documents. By the 3rd century BC, the evidence is clear that people in China understood the individual nature of fingerprints and used them as personal identifiers in official seals. Even before that, however, potters and artists from across the ancient world left their indelible marks on their works with thumbprints, possibly to uniquely identify work as theirs (Figure 7.2.1). For example, fingerprints have been identified on Stone Age ceramic artifacts, monuments, and lithographs; an indication that people far back into our pre-history at least peripherally understood the uniquely personal character of fingerprints. Ceramic and forensic experts have recently worked with archeologists to try to use fingerprints on unearthed ancient pottery to learn how many potters may have been responsible for producing the artifacts found at a particular site.
Possibly the first recorded case of the true forensic use of fingerprints, however, comes from **medieval Rome** where the 10th century Roman attorney Quintilian was able to show that bloody hand prints found at a crime scene were meant to frame a blind man for the murder of his mother by the true murderer. In the 1600s, however, there were several important fundamental developments in understanding the unique nature of fingerprints.

In 1684, the Dutch scientist Nehemia Grew, reported his studies of the ridges and sweat pores found on human hands and fingers, features he called "little fountains". His work was elaborated in 1686 by Prof. Marcello Malphigi from the University of Bologna, when he provided a more detailed picture of the ridge patterns found on fingers. An interesting recent discovery from this time period came when modern workmen were remodeling a room at Hampton Court in England and found 17 complete hand prints in the underlying plaster from workmen who "signed" their work when the room was remodeled in 1690 for King William III (Figure 6.2.2).

By the early 1800s, naturalists clearly had begun to understand the origins and individuality of fingerprints. In 1823, Prof. John Evangelist Purkinji of the University of Breslau, published a thesis on different types of fingerprint patterns, and in 1858, Sir William Hershel, Chief Administrative Officer in Bengal, India, followed a local Indian custom and used fingerprints to sign contracts with local workers. Hershel also realized from his observations that spanned over six decades that the fingerprint pattern we are born with persists throughout life, and referred to this important concept as the **Principle of Persistency**. This principle says that once our fingerprints are formed during prenatal development, these patterns then remain unchanged throughout our lives and often last even well beyond death to the latter stages of decay.

One of the big problems in the criminal punishment system of the nineteenth century that Hershel and others were particularly concerned about had to do with recognizing repeat offenders. Like today, nineteenth century societies wanted to levy more severe punishments on a criminal who repeated their offenses. The problem was how to be sure that it was the same offender each time. Photographs were not reliable and a system of measurements of our physical features (e.g., distance between the eyes, size of nose, length of fingers, etc.), known as the **Bertillion System**, was highly problematic and later abandoned completely. Herschel, however, saw the clear advantages of using fingerprints to identify repeat criminals and advocated fingerprint use in the personal identification records of prisoners.

While Hershel sought to use fingerprints to identify convicted criminals, what was really needed for fingerprints to become particularly useful in forensic investigations was some system for the classification of the lifelong ridge patterns so that large numbers of prints and files could be quickly and easily compared. One of the first attempts at this task came from the work of Dr. Henry Faulds, British Surgeon-Superintendent of the Tsukiji Hospital in Tokyo, who developed the first...
systematic method of classification. Dr. Faulds also clearly recognized the use of fingerprints in forensic investigations and wrote "When bloody fingerprints or impressions on clay, glass, etc. exist, they may lead to the scientific identification of criminals..... There can be no doubt as to the advantage of having, beside their photograph, a copy of the forever unchangeable finger furrows of important criminals" (Nature, October 28, 1880). He recognized the value of latent prints (prints not visible to the naked eye) and used his expertise to exonerate a staff member at his hospital who was incorrectly charged with robbery. Dr. Faulds is today recognized as the "father of fingerprinting", although this recognition didn't come until nearly half a century after his death.

**THE CASE OF THE WILLS WEST**

In 1903, Will West was admitted to the Leavenworth Penitentiary in Kansas. As part of his induction, a series of measurements were taken to see if he was a repeat offender - and, sure enough, a card listed someone as William West with essentially the same set of measurements and photographic likeness. But with a little more examination, however, it was learned that William West was already at Leavenworth serving a life term for murder! The fingerprints of the two men were, however, clearly different. While this is an interesting case, it probably didn't play a particularly important role in establishing fingerprint analysis in the United States as an important basis of criminal identification. (pictures from members.aol.com/SVG2254/West.htm)

In "Life on the Mississippi" (1883) and later in "Pudd'n Head Wilson" (1893), Mark Twain brought to literature the use of fingerprints in criminal justice. In real life, however, Juan Vucetich of the Argentine Police in 1891, was one of the first to use fingerprints to identify a woman who had murdered her two sons and then took her own life in an attempt to frame someone else. Her bloody handprint, however, was found on the door post, thereby both exonerating the framed person and showing the woman as the true murderer. At about the same time, Sir Francis Galton, published a book, entitled "Fingerprints" that reiterated the individuality (uniqueness) and permanence of fingerprints and presented an alternative to Dr. Faulds’ classification system. Galton's system, however, was itself soon replaced in 1896 by Sir Edward Richard Henry's fingerprint classification system. This system, first adopted by Scotland Yard in 1901, is essentially the same system that is still in used in many places today.

Fingerprint use as personal

**Brief on Fingerprints: Timeline**

- >3,000 BC - Ancient fingerprints on pottery
- 300 BC - Chinese use of fingerprints for documents
- 1,100 AD - Quintilian uses fingerprints in murder case.
- 1684 - Nehemia Grew reports on ridges and pores.
- 1823 - J.E. Purkinji describes ridge detail.
- 1858 - Hershel reports persistency of fingerprint detail throughout life.
- 1880 - H. Faulds proposes fingerprint use in forensic investigations, latent prints, and proposes a classification system.
- 1891 - J. Vucetich uses fingerprints to solve murder case.
- 1892 - F. Galton expands on the use of fingerprints and proposes a classification system.
- 1902 - First American use of fingerprints.
- 1977 - FBI begins computerized AFIS system.
- 1999 - FBI begins completely digital fingerprint system for submission, storage, and search (IAFIS).
Identifiers in the United States really began in 1902 when the New York Civil Service Commission and, in 1903, the New York State Prison system began using fingerprints for the identification of convicted criminals. At about the same time (1902) in a related development, R. Fischer presented his related work on the furrows of the human lips for individual identification, a field known as cheiloscopy. This work culminated in 1968 when the lip prints of over 1,300 people were examined at Tokyo University with the conclusion that lip prints, like fingerprints, are also unique to an individual.

Finally, in 1977 the FBI began the use of its Automated Fingerprint Identification System (AFIS) using digital scans of fingerprints. This system was upgraded in 1996 to allow for the computerized searches of the entire AFIS fingerprint database, and then modified again in 1999 with the formation of the Integrated Automated Fingerprint Identification System (IAFIS), that provided for the automated digital computer submission, storage, and search of the national FBI fingerprint database. Today, federal and state agencies can receive answers to requests for matching criminal fingerprint patterns with well over 55 million fingerprint records on file within two hours of submission.

**Skin: The Amazing Organ**

Our skin is the largest organ system in the human body weighting, on average, 25 pounds and covering about 20 ft² in area. Our skin is part of a larger system, called the integumentary system, that forms the outer “boundary” of our bodies and includes our skin, hair and nails (the latter two are considered “derivatives” of our epidermis). It consists of an array of various tissues and structures that function together for the protection and regulation of underlying organs and gets about one-third of all the oxygenated blood that heaves the heart. In particular, the skin helps to regulate the temperature of our bodies in the face of constantly changing thermal environments, controls moisture loss, protects us from physical impact and wear, provides a barrier to the entry of unwanted substances and agents into our bodies from a hostile environment (such as bacteria and viruses), and serves as a highly sensitive sensory organ for the body. It allows us to feel the lightest touch and yet withstand some pretty significant impact and abrasion forces. It’s tough, durable and constantly being repaired and replaced.

The skin contains a variety of specialized cells and structures (Figure 7.2.3). Our skin has three major layers, although each is often broken into smaller sublayers. The lowest layer is referred to as the subcutaneous layer (or more accurately called the hypodermis) and is composed largely of fat and connective tissue that contains larger blood vessels and nerves. The middle layer, referred to as the dermis, is composed mostly collagen (protein) fibers, elastic tissue, and reticular fibers (crosslinked fibers that form a fine supporting meshwork). The dermis is also the place where the hair follicles, sebaceous (oil) glands, eccrine (sweat) glands, apocrine (scent) glands, and hair erect or muscles are found. Additionally, nerves and smaller blood vessels run through this layer and transmit information about temperature, touch, pressure, and sometimes pain to our brains. More will be presented later on hair and how it grows from the follicles located in these dermal layers. The main structural function of the dermis is to support and nurture the layer lying above it. The outermost layer of our skin is called the epidermis and ranges in thickness from very thin on our eyelids (about 0.05 mm) to rather thick on the palms of our hands and the soles of our feet (around 1.5 mm thick). It is this layer that also contains melanin, the pigment responsible for skin coloration. At the lowest portion of the epidermis, often referred to as the “generating layer” (stratum basale), column-like cells constantly divide and push previously formed cells towards the surface, causing these cells to flatten out and ultimately die in the process. The very top layer of the epidermis (stratum corneum), the part directly in contact with the outside world, is composed entirely of 25 to 30 layers of dead cells that stay at the surface for about two weeks before being shed and replaced from layers below.
DEVELOPMENT AND STRUCTURES OF FINGERPRINTS

On certain surfaces of our skin, particularly our hands and feet, a tightly packed series of ridges are formed early in our development. These regular patterns of ridges usually begin to be observed between the third and fifth months of our prenatal development and grow in complexity as the fetus develops. Once established, these patterns of ridges stay with us unchanged throughout life, simply expanding uniformly to a larger size as we grow and develop. These “friction” ridges serve to greatly increase the skin’s surface area and, therefore, increase the gripping ability of our hands and
feet, especially on smooth and wet surfaces, and to increase the sensitivity of our touch sense (Figure 7.2.4). These ridges are believed to originate during our prenatal development from the buckling of the basal cell layer of the fetal epidermis as the cells in this layer grow rapidly and do not have sufficient space to spread out so the layer end up permanently bending and buckling to form the ridges that we see at the surface of the skin.

The tops of the ridge patterns on our fingers are called *ridges* and the adjacent lower valleys are called *furrows*. The surface of these ridges are dotted with the openings for sweat glands that are located in the deeper (dermal) layers of the skin and serve to help remove cellular waste products, including salt and urea, and to regulate body temperature. Each ridge unit consists of a sweat gland in a folded regular pattern with nearly 2,700 ridge units per square inch of friction skin. The observed pattern of our fingerprints arises from our epidermal layer, although the pattern is formed deeper at the interface between the top of the dermal layer and the lowest epidermal layer, called the *stratum basale* - the base layer of the epidermis (Figure 7.2.3). Because the pattern of our ridges arise from these lower dermal levels of our skin, fingerprint patterns cannot be easily altered, even when the epidermal layers of the skin are injured. An injury must penetrate and change the deeper dermal layer to make a lasting impact on someone’s fingerprint pattern. Fingerprints may, however, be affected by deep trauma or disease. For example, eczema, psoriasis, dermatopathia pigmentosa reticularis (DPR), or a disease called scleroderma may lead to either distorted or even the complete lack of fingerprints (Fig. 7.2.5). Additionally, treatment with a common anti-cancer drug, Capecitabine, in some instances leads to a disappearance of a person’s fingerprints.

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**FINGERPRINT PATTERNS**

The ridges on our fingers form interesting, regular, and unique patterns that can be classified into overall pattern groupings and further into sets of smaller identifiable characteristics. Several systems of classification exist, although the Henry System was the most commonly encountered until relatively recently. While the Henry System has now largely been replaced by digital automated systems, many of the general features of the system remain important in identifying and comparing fingerprints.

Fingerprint classification systems typically begin by identifying three basic patterns: the *loop*, the *arch*, and the *whorl*, shown in Figure 7.2.6. An *arch* pattern, found in about 5% of all fingerprints, has ridges beginning at one side of the fingerprint and running completely to the other side of the fingerprint without a backwards turn. In contrast, *loop* patterns, found in about 60% to 70% of fingerprints, contain ridge lines that enter on one side of the fingerprint, run towards the middle of the print, and then curve backwards to exit on the same side that they entered the pattern. *Whorls*, found in about 25-35% of fingerprints, contain ridges that complete at least one 360°
“circuit” in the pattern, although not always forming a regular circular pattern (see the double loop whorl pattern in Fig. 7.2.6 as an example).

Two important additional features of fingerprints also help to readily define these three basic patterns: the \textit{delta} and the \textit{core}. These two features are probably most easily understood by examining more closely a loop pattern, such as that shown in Figure 7.2.7. Where a loop pattern reaches its farthest point towards the middle of the print and begins to turn backwards, the innermost ridge of the curve is referred to as the \textit{core}. If, instead, we look at the ridge lines that enter the print from the side opposite from where the loop enters and exits, we see that where these ridges encounter the looped ridges, they are deflected either downwards or upwards around the looped ridges. This is similar to the effect observed in a flowing stream that encounters a rock in the middle of it’s path: some of the water is deflected to the left and some to the right. The point of ridge divergence where the upward and downward deflected ridges meet the looping ridges (the rock in the stream) forms a \textit{delta} (a small triangular region). Often, a small island is also observed at the center of the delta. If a line is draw from the top of the core to the delta point, it intersects a number of ridges between these two features. The number of ridges between these two features is known as the \textit{ridge count}. 

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fingerprint_patterns.png}
\caption{Main pattern systems in human fingerprints: arch (plain and tented arch), loop (plain, radial, and ulnar), and whorl (double loop, pocked/pocket, plain, or mixed/accidental) \hspace{1cm} \textit{Figure 7.2.6}.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{loop_features.png}
\caption{Core and delta features illustrated for a loop pattern. The number of ridges that are between the core and the delta (shown at left) defines the ridge number of the print (shown with a ridge count of 8). \hspace{1cm} \textit{Figure 7.2.7}.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{radial_ulnar_loop.png}
\caption{Radial loop (right) and ulnar loop (left) \hspace{1cm} \textit{Figure 7.2.8}.}
\end{figure}
three basic patterns of arch, loop, and whorl are also defined specifically by their core and delta features. Loop patterns show one delta and one core feature, whorl patterns have at least two deltas, and plain arches have no deltas.

These broadest three patterns are, however, often broken down into several more detailed groups. Arches are often broken down into plain and tented arches. The ridges in a plain arch pattern flow relatively smoothly across the print while a tented arch has a significantly “upward” pushed pattern that resembles a tent pole and where one ridge stands up at least at a 45° or greater angle (and usually contains a delta). Loops can be plain, radial (where the starting, open part of the loop, or it’s “tail”, points towards the thumb – or the radial bone), or ulnar (where the open part of the loop points away from the thumb – or towards the ulnar bone), as shown in Figure 7.2.8 [an easy way to remember where the radius bone joins the hand is to remember “Teddy Roosevelt” – the Thumb and Radius are on the same side]. Radial loops are very uncommon and usually found on the index finger. Finally, whorls can be broken down into plain whorls, double loop whorls, accidental (mixed) whorls, and central pocket (pocked) loop whorls.

Upon closer examination of the patterns made by the ridges on our fingers, we find that they are often not just simple lines but are far more complex. The lines vary in length and thickness, branch and fuse together, end and start abruptly, and form a rich level of detail within the general loop, arch and whorl patterns. The information obtained from fingerprints are often divided into three levels of detail. The first level (not surprisingly, called level 1) describes the overall structural information found in the pattern (e.g., arch, loop, double loop whorl, etc.). Level 2 contains information about how the individual friction ridges are arranged in terms of their starting and stopping, fusing, branching and other features –referred to as minutiae. The final level (level 3), describes the finest details about individual ridges, such as their thicknesses, edge shapes, location of pores, and other fine detail information.

There are a number of minutial features that can be identified in a fingerprint, just a few of these are shown in figure 7.2.9. For example, the point where a single ridge splits into two new ridges is called a bifurcation while a single friction ridge that simply ends is called an ending ridge point. A short ridge enclosed by other ridges is referred to as either an island or a ridge dot (when the ridge’s length is approximately the same as its width it’s called a dot). Many other types of minutiae exist and help define the individual characteristics of a fingerprint. Both the type and location of each of these minutial features are very important in characterizing and comparing fingerprints.

The most detailed level of a fingerprint (level 3) looks at the fine characteristics of an individual ridge unit. This level of detail is typically not currently included in many forensic visual...