Crime Scene Investigation and Forensics
An Introductory Text
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Bloodstain pattern analysis

Bloodstain pattern analysis (BPA) is one of several specialties in the field of forensic science. The use of bloodstains as evidence is not new; however, the application of modern science has brought it to a higher level. New technologies, especially advances in DNA analysis, are available for detectives and criminologists to use in solving crimes and apprehending offenders.

The science of bloodstain pattern analysis applies scientific knowledge from other fields to solve practical problems. Bloodstain pattern analysis draws on the scientific disciplines of biology, chemistry, mathematics and physics. If an analyst follows a scientific process, this applied science can produce strong, solid evidence, making it an effective tool for investigators.

Results of BPA

Not every result of BPA will qualify as incontrovertible evidence, but the following are some things a bloodstain pattern analyst may be able to determine conclusively and state as fact:

• Movement and direction of persons or objects while they were shedding blood.
• Position of persons or objects during bloodshed.
• Movement of persons or objects after bloodshed.
• The mechanism or object used to create a specific pattern.
• The direction a stain was traveling when it was deposited.
• The area of origin of an impact pattern.
• The minimum number of impacts during an incident.
• The sequence of events.

A basic understanding of blood spatter analysis allows first responding officers and investigators alike to assist in correctly collecting and preserving bloodstain data at the scene. If they know what they have at the scene, then based on their department policy they should know what they need to do next. Bloodstain pattern analysis requires sufficient education and training to be an effective investigative technique, which not all law enforcement officers attending a crime scene will necessarily have.

Bloodstain analysts receive specialized training. The foundation course in bloodstain pattern analysis is the Basic Bloodstain Pattern Analysis Course. This is taught at many government and private institutions. The course criteria were developed by the International Association of Bloodstain Pattern Analysts (IABPA) with the following stated purpose:

A course of instruction designed for investigators, crime scene technicians, forensic technicians, and others involved in criminal and medical-legal investigations and crime scene analysis. The course is intended to develop a fundamental knowledge of the discipline of bloodstain pattern analysis. The course should illustrate to the student basic principals [sic] of bloodstain pattern analysis and the practical application of the discipline to actual casework. The course syllabus is not intended to create an "instant" expert.

Beyond this basic course are conferences, seminars, and courses such as the Maths and Physics for BPA and The Advance Bloodstain Pattern Analysis Course, both of which are provided by the Ontario Police College (OPC) and the Royal Canadian Mounted Police (RCMP). These two institutions also have Bloodstain Analyst Understudy programs. The International Association for Identification (IAI) provides its own certification in bloodstain pattern analysis.

In addition to formal study of the subject, practical experience and experimentation is paramount in the development of a skilled bloodstain pattern analyst.
Bloodstain pattern categories

There are several different thoughts on how to classify and define bloodstain patterns. The following is one accepted way of categorizing them based on the mechanism that created the stain. The three stain groups are: Passive, Projected, and Transfer/Contact. The definitions used below are from the suggested IABPA terminology list:

Passive bloodstains
Passive bloodstains are those stains created by the force of gravity.

• Passive Drops - Bloodstain drop(s) created or formed by the force of gravity acting alone.
• Drip Pattern - A bloodstain pattern which results from blood dripping into blood.
• Flow Pattern - A change in the shape and direction of a bloodstain due to the influence of gravity or movement of the object.
• Pool Pattern - A bloodstain pattern formed when a source of blood is stationary for a period of time.

Projected bloodstains
A projected stain occurs when some form of energy has been transferred to a blood source.

• Low Velocity Impact Spatter (LVIS) - A bloodstain pattern that is caused by a low velocity impact\force to a blood source.
• Medium Velocity Impact Spatter (MVIS) - A bloodstain pattern caused by a medium velocity impact\force to a blood source. A beating typically causes this type of spatter.
• High Velocity Impact Spatter (HVIS) - A bloodstain pattern caused by a high velocity impact\force to a blood source such as that produced by gunshot or high-speed machinery.
• Cast-Off Pattern - A bloodstain pattern created when blood is released or thrown from a blood-bearing object in motion.
• Arterial Spurting (OR Gushing) Pattern - Bloodstain pattern(s) resulting from blood exiting the body under pressure from a breached artery.
• Back Spatter - Blood directed back towards the source of energy or force that caused the spatter.
• Expiratory Blood - Blood that is blown out of the nose, mouth, or a wound as a result of air pressure and/or air flow which is the propelling force.

Transfer/Contact bloodstains
A transfer or contact stain is produced when an object with blood comes in contact with an object or surface that does not have blood. It may be possible to discern the object that left the blood impression.

• Wipe Pattern - A bloodstain pattern created when an object moves through an existing stain, removing and/or altering its appearance.
• Swipe Pattern - The transfer of blood from a moving source onto an unstained surface. Direction of travel may be determined by the feathered edge.

As indicated above, there are other terms currently used in BPA and different ways of classifying bloodstain patterns. For example there is a debate over the misnomer of the LVIS, MVIS, and HVIS as it relates to the physical term "velocity". A sub-committee of the SWGSTAIN has been tasked with addressing the terminology issues and develop a taxonomy for bloodstain patterns.
"Velocity" impact stains

Contrary to what the name states, the terms low-, medium-, and high-velocity impact spatter do not describe the velocity of the blood droplets as they fly through the air. The variation in the "velocity" is meant to describe the amount of energy transferred to a blood source in order to create the stains. Velocity is a speed (m/s) with a direction. Often the terms force and energy are quoted in conjunction with the unit ft/s or m/s which is incorrect. Force is related to velocity and mass (N or 1 kg ·m·s⁻²). Energy (work) is related to the force exerted on an object (J or N·m or kg·m²·s⁻²). As indicated above, there has been great debate over these terms and their definitions. Below is one method of differentiating low-, medium-, and high-velocity impact spatter.

Low velocity impact spatter

Low velocity impact spatter (LVIS) is generally produced when objects traveling less than 1.5 m/s come in contact with a blood source. The preponderance of stains is generally larger than 3 mm in diameter.

Medium velocity impact spatter

Medium velocity impact spatter (MVIS) is generally produced when objects traveling between 1.5 m/s and 7.5 m/s come in contact with a blood source. The preponderance of stains is generally between 1 mm and 3 mm in diameter. Mechanisms that could produce this type of pattern include blunt force trauma or cutting/stabbing actions.

High velocity impact spatter

High velocity impact spatter (HVIS) is generally produced when objects traveling greater than 30 m/s come in contact with a blood source. The preponderance of stains is generally smaller than 1 mm in diameter. This pattern often has a mist-like appearance. High velocity patterns may be created by gunshots or explosives, but may also be caused by industrial machinery, coughing, or sneezing.

Blood

Blood is a tissue that is circulated within the body to assist other parts of the body. This connective tissue has specialized cells that allow it to carry out its complex functions. For a healthy person, approximately 8% of their total weight is blood. For a 70-kg (154-lb.) individual, this equates to 5.6 L (12 US pints).

Biological considerations

Blood contains three components suspended within plasma. The three components are erythrocytes, leukocytes, and platelets.

- Erythrocytes - also known as red blood cells, are transporters. The role of erythrocytes is to transport oxygen. To do this it produces great quantities of hemoglobin, which gives it the distinct red colour. Blood that has passed through the heart and been oxygenated (in the arteries) tends to have a brighter shade of red as opposed to blood that is returning to the heart (in the veins). There are about 30 trillion erythrocytes circulating in the human blood at any given time.
- Leukocytes - also known as white blood cells, are defenders. The role of leukocytes is to defend the body against harmful bacteria and microorganisms. There are five different types of leukocytes all having different sizes, shapes, structures, and functions. Leukocytes fight infection and disease. There are about 430 billion leukocytes circulating in the human blood at any given time (~1 per 700 erythrocytes).
- Platelets - are pieces of larger cells that have broken off in the bone marrow. These bits of cytoplasm are enclosed by a membrane and do not have a nucleus. They play a major role in haemostasis (control of bleeding) by plugging up a breach in a vessel.
Plasma is a yellowish fluid that carries the suspended erythrocytes, leukocytes, and platelets. It is composed of water (92%), proteins (7%), and other materials such as salts, waste, and hormones, among others. Plasma makes up about 55% of blood. The remaining 45% is blood cells and platelets. Because plasma is lighter than the blood cells and platelets, it can be easily separated. Plasma does not separate from blood cells in the body because it is in a constant state of agitation.

**Physical considerations**

In physics there are two continuous physical states of matter, solid and fluid. Once blood has left the body it behaves as a fluid and all physical laws apply.

- **Gravity** - is acting on blood (without the body's influence) as soon as it exits the body. Given the right circumstances blood can act according to ballistic theory.
- **Viscosity** - is the amount of internal friction in the fluid. It describes the resistance of a liquid to flow.
- **Surface tension** - is the force that gives the ability to blood to maintain its shape. When two fluids are in contact with each other (blood and air) there are forces attracting all molecules to each other.

**Blood spatter flight characteristics**

Experiments with blood have shown that a drop of blood tends to form into a sphere in flight rather than the artistic teardrop shape. This is what one would expect of a fluid in freefall. The formation of the sphere is a result of surface tension that binds the molecules together.

This spherical shape of blood in flight is important for the calculation of the angle of impact (incidence) of blood spatter when it hits a surface. That angle will be used to determine the point from which the blood originated which is called the Point of Origin or more appropriately the Area of Origin.

A single spatter of blood is not enough to determine the Area of Origin at a crime scene. The determination of the angles of impact and placement of the Area of Origin should be based on the consideration of a number of stains and preferably stains from opposite sides of the pattern to create the means to triangulate.

**Determining angles of impact**

As mentioned earlier a blood droplet in freefall has the shape of a sphere. Should the droplet strike a surface and a well-formed stain is produced, an analyst can determine the angle at which this droplet struck the surface. This is based on the relationship between the length of the major axis, minor axis, and the angle of impact.

A well-formed stain is in the shape of an ellipse (see figure 1). Dr. Victor Balthazard, and later Dr. Herbert Leon MacDonell, realized the relationship of the width-length ratio of the ellipse was the function of the sine of the impact angle. Accurately measuring the stain will easily result in the calculation the impact angle.
Fig. 1 Upward moving bloodstain showing proper ellipse placement.

Fig. 2 Angles of Impact

Because of the three dimensional aspect of trajectories there are three angles of impact, $\alpha$, $\beta$, and $\gamma$. The easiest angle to calculate is *gamma* ($\gamma$). Gamma is simply the angle of the bloodstain path measured from the true vertical (plumb) of the surface (see figure 2 showing plumb line and extended angle from stain.)

The next angle that can be quite easily calculated is *alpha* ($\alpha$). Alpha is the impact angle of the bloodstain path moving out from the surface (see figure 2 with alpha at the top by the stain.) The third angle to be calculated is *beta* ($\beta$). Beta is the angle of the bloodstain path pivoting about the vertical (z) axis (see figure 2 with beta extended to the floor). All three angles are related through trigonometry through the equation quoted below.

**Calculating the $\alpha$ angle**

$$1 = \text{length of ellipse (major axis)}$$

$$w = \text{width of ellipse (minor axis)}$$

$$\alpha = \text{angle of impact}$$

The relationship between these variables is:

$$\sin \alpha = \left( \frac{w}{l} \right)$$

Therefore:

$$\alpha = \arcsin \left( \frac{w}{l} \right)$$
Relationship between angles $\alpha$, $\beta$, and $\gamma$

\[ \tan \beta = \frac{\tan \alpha}{\sin \gamma} \]

Accurately measuring the stain and calculating the angle of impact requires due diligence of the analyst. In the past analysts have used a variety of instruments. Methods currently used include:

- Viewing loop with an embedded scale in 0.2 mm increments or better that is placed over the stain. The analyst then uses a scientific calculator or spreadsheet to complete the angle calculations.
- Bloodstain Pattern Analysis (BPA) software that superimposes an ellipse over a scaled close-up image of an individual bloodstain. The programs then automatically calculates the angles of impact.

Using software produces a very accurate result that is measurable and reproducible.

Point and area of convergence

To determine the point/area of convergence an analyst has to determine the path the blood droplets travelled. The tangential flight path of individual droplets can be determined by using the angle of impact and the offset angle of the resulting bloodstain. "Stringing" stains is a method of visualizing this. For the purpose of the point of convergence, only the top view of the flight paths is required. Note that this is a two-dimensional (2D) and not a three-dimensional (3D) intersection.

- The point of convergence is the intersection of two bloodstain paths, where the stains come from opposite sides of the impact pattern. (see figure 3)
- The area of convergence is the box formed by the intersection of several stains from opposite sides of the impact pattern. (see figure 4)

In the past, some analysts have drawn lines along the major axes of the stains and brought them to an area of convergence on the wall. Instead of using a top-down view, they used a front view. This provides a false point/area of convergence.
Area of origin

The area of origin is the area in three-dimensional space where the blood source was located at the time of the bloodletting incident. The area of origin includes the area of convergence with a third dimension in the z direction. Since the z-axis is perpendicular to the floor, the area of origin has three dimensions and is a volume.

The term point of origin has also been accepted to mean the same thing. However it has been argued, there are problems associated to this term. First, a blood source is not a point source. To produce a point source the mechanism would have to be fixed in three-dimensional space and have an aperture where only a single blood droplet is released at a time, with enough energy to create a pattern. This does not seem likely. Second, bodies are dynamic. Aside from the victim physically moving, skin is elastic and bones break. Once a force is applied to the body there will be an equal and opposite reaction to the force applied by the aggressor (Newton's third law of motion). Part of the force will move the blood source, even a millimetre, and change the origin while it is still producing blood. So the source becomes contained in a three-dimensional volume, or region.

As with the area of convergence, the area of origin is easily calculated by using BPA software. There are other longer, mathematical methods of determining the area or origin, one of which is the tangential method.

IABPA definition:
- **Point (Area) of Origin** - The common point (area) in three-dimensional space to which the trajectories of several blood drops can be retraced. (see figure 5)

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**Photography**

Crime scene photography has some unique requirements. In the event there is a bloodletting scene, the basics are still required but special attention must be given to the bloodstains. The current means of documenting the scene include, 35 mm (B&W, colour, and specialty film), digital cameras (such as Nikon D200 among others), and video (Hi-8, DV, and other formats). Each method has its pros and cons. Often the scene is documented using multiple methods. (Videography has been included here because it follows the same principles and provides crime scene images.)

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There are three types of crime scene photos:

- **Overall** – wide-angle images (28–35 mm range) that capture the scene as it is. This type of image provides anyone who has not been in the scene a good overall layout.
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- **Mid-range** – images taken with a normal lens (45–55 mm range) give greater detail than the overall shots. In the case of a bloodletting scene, the mid-range image could capture a single bloodstain pattern.

- **Close-up** – images taken with a macro lens giving the greatest amount of detail. For example, a medium velocity impact pattern can contain thousands of individual stains where there is a preponderance of small stains (1–3 mm in diameter) some of which require individual images.

Many times an analyst cannot attend a bloodletting scene. Therefore, the analyst may have to do all his work based on the crime scene images and notes of the person who attended. An appropriate sized scale should be in overall, mid-range, and close-up images. For overall images the scales should be parallel and perpendicular to the floor. This provides the analyst, and anyone else who looks at the images, a proper perspective on what they are observing. (Note: in some cases overall and mid-range images are taken with and without a scale.)

**In popular culture**

- Serial killer Dexter Morgan of the Dexter novels and Showtime series is a blood spatter analyst for the Miami-Dade County Police Department.
- Catherine Willows is a blood spatter analyst on the CBS series *CSI: Crime Scene Investigation*.

**References**

- Bevel, Tom; Gardner, Ross M. Bloodstain Pattern Analysis With an Introduction to Crimescene Reconstruction, 3rd Ed. CRC Press 2008
- Sutton, Paulette T., Bloodstain Pattern Interpretation, Short Course Manual, University of Tennessee, Memphs TN 1998

**External links**

- FBI Laboratory Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) [2]
- International Association of Bloodstain Pattern Analysts (IABPA) [3]

**References**

[1] http://books.google.ca/books?id=aM6hNdiHR5gC
Ballistics

Ballistics (gr. βάλλειν (‘ba’llein’), "throw") is the science of mechanics that deals with the flight, behavior, and effects of projectiles, especially bullets, gravity bombs, rockets, or the like; the science or art of designing and accelerating projectiles so as to achieve a desired performance.

A ballistic body is a body which is free to move, behave, and be modified in appearance, contour, or texture by ambient conditions, substances, or forces, as by the pressure of gases in a gun, by rifling in a barrel, by gravity, by temperature, or by air particles. A ballistic missile is a missile only guided during the relatively brief initial powered phase of flight, whose course is subsequently governed by the laws of classical mechanics.

Gun ballistics

Gun ballistics is the study of projectiles from the time of shooting to the time of impact with the target. Gun ballistics is often broken down into the following four categories, which contain detailed information on each category:[1]

- **Internal ballistics**, (sometimes called interior ballistics) the study of the processes originally accelerating the projectile, for example the passage of a bullet through the barrel of a rifle.[2]
- **Transition ballistics**, (sometimes called intermediate ballistics) the study of the projectile's behavior when it leaves the barrel and the pressure behind the projectile is equalized.[3]
- **External ballistics**, (sometimes called exterior ballistics) the study of the passage of the projectile through a medium, most commonly earth's atmosphere.[4]
- **Terminal ballistics**, the study of the interaction of a projectile with its target, whether that be flesh (for a hunting bullet), steel (for an anti-tank round), or even furnace slag (for an industrial slag disruptor).[5]

Forensic ballistics

Forensic ballistics involves analysis of bullets and bullet impacts to determine information of use to a court or other part of a legal system. Separately from ballistics information, firearm and tool mark examinations ("ballistic fingerprinting") involve analysing firearm, ammunition, and tool mark evidence in order to establish whether a certain firearm or tool was used in the commission of a crime.

See also

- Ballistic conduction (related to electron transport)
- Gunshot residue
- Hydrostatic shock
- Physics of firearms
- Trajectory
- Vaporific Effect
- Gunshot injury
- Stopping Power
- Peter Bielkowicz
- Microscopes and ballistics
Ballistic fingerprinting refers to a set of forensic techniques that rely on marks that firearms leave on bullets to match a bullet to the gun it was fired with.[1] It is a subset of forensic ballistics (the application of ballistics to legal questions) and internal ballistics (the study of events between the firing of a gun and the bullet leaving the barrel).[1]

**History**

Rifling, which first made an appearance in the 15th century, is the process of making grooves in gun barrels that imparts a spin to the projectile for increased accuracy and range. Bullets fired from rifled weapons acquire a distinct signature of grooves, scratches, and indentations which are of value for matching a fired projectile to a firearm.

The first firearms evidence identification can be traced back to England in 1835 when the unique markings on a bullet taken from a victim were matched with a bullet mold belonging to the suspect. When confronted with the damning evidence, the suspect confessed to the crime. Alexandre Lacassagne was the first scientist to try to match an individual bullet to a gun barrel.

The first court case involving firearms evidence took place in 1902 when a specific gun was proven to be the murder weapon. The expert in the case, which was reviewed by Mr. Justice Oliver Wendell Holmes in *Commonwealth v. Best*, 180 Mass. 492 (1902)[2] , had read about firearm identification, and had a gunsmith test-fire the alleged murder weapon into a wad of cotton wool. A magnifying glass was used to match the bullet from the victim with the test bullet.

Calvin Goddard, physician and ex-army officer, acquired data from all known gun manufacturers in order to develop a comprehensive database. With his partner, Charles Waite, he catalogued the results of test-firings from every type of handgun made by 12 manufacturers. Waite also invented the [[ComparisoSearch Results

References


External links

- http://ballistics.org/International Ballistics Society

A forensic ballistics experiment

Controversial bullet from the John F. Kennedy assassination.
In 1925 Goddard wrote an article for the Army Ordnance titled "Forensic Ballistics" in which he described the use of the comparison microscope regarding firearms investigations. He is generally credited with the conception of the term "forensic ballistics," though he later admitted it to be an inadequate name for the science.

In 1929 the St. Valentine's Day Massacre led to the opening of the first independent scientific crime detection laboratory in the United States.

**Techniques**

Ballistic fingerprinting techniques are based on the principle that all firearms have inevitable variations due to marks left by the machining process, leaving shallow impressions in the metal which are rarely completely polished out. Also, normal wear and tear from use can cause each firearm to acquire distinct characteristics over time.

**Gross differences**

The simplest considerations are the gross differences. A 10 mm bullet, for example, could not have been fired from a 9 mm barrel.

**Striations**

When a bullet is fired through a rifled barrel, the raised and lowered spirals of the rifling etch fine grooves called "striations" into the bullet. These can be matched with the barrel through which the bullet was fired. Examiners distinguish between striations common to all guns of a particular type ("class characteristics") and those unique to a particular gun ("individual characteristics").[1]

The class characteristics depend upon the type of rifling in the barrel, which varies among manufacturers and models in number and shape of the grooves, twist rate, and direction. Colt, for example, traditionally uses a left-hand twist, while Smith and Wesson uses a right hand twist; a current production M16 rifle uses a 1 in 7 inch twist, while most civilian AR-15s and the current Mini-14 use a 1 in 9 inch twist. Marlin Firearms use a distinctive 16-groove Micro-Groove rifling in many of their firearms, while the M1903 Springfield rifle had two, four, or six grooves depending on the manufacturer. Polygonal rifling may leave striations that are difficult to match to a particular barrel.

Individual characteristics are caused by imperfections in the rifling process and tools, but also by the wear and tear caused by regular use, and can therefore change over time. Criminals or those concerned with government intrusion in privacy sometimes attempt to alter a gun's individual characteristics by changing or shortening the barrel, or by rubbing its interior with a steel brush.[3]
Breech markings
Marks on the cartridge case can be matched to marks in the chamber and breech. For a number of reasons, Cartridge cases are often easier to identify than bullets. First, the parts of a firearm that produce marks on cartridge cases are less subject to long-term wear, and second, bullets are often severely deformed on impact, destroying much of the markings they acquire.

Shotguns
Ballistic fingerprinting of bullets does not work with firearms such as shotguns that fire shot-containing cartridges. In many cases the shot rides inside a plastic sleeve that prevents it from ever touching the barrel, and even in cases where the shot does touch the barrel, the random movement of the shot down the barrel will not leave any consistent marks. But shotgun cases can still be examined for firing pin marks and the like.\[1\]

Ballistic fingerprinting aids

Databases
Some localities, particularly Maryland, have attempted to build up a large database of "fingerprints"; in the case of the Maryland law, all new firearms sales must provide a fired case from the firearm in question to the Maryland State Police, who photograph it and log the information in a database. The Maryland State Police wrote a report critical of the program and asking the Maryland General Assembly to disband it, since it was expensive and had not contributed to solving a single crime.\[6\] Subsequently however, the database did provide evidence used to obtain one murder conviction at an estimated cost of 2.6 million dollars per conviction.\[5\]

A California Department of Justice survey, using 742 guns used by the California Highway Patrol as a test bed, showed very poor results; even with such a limited database, less than 70% of cases of the same make as the "fingerprint" case yielded the correct gun in the top 15 matches; when a different make of ammunition was used, the success rate dropped to less than 40%.

Bullet marking
There have been several proposals for the mandated marking of bullets to aid in ballistic fingerprinting, and some jurisdictions have passed legislation to that effect. California, for instance, passed a bill AB 1471 which requires all new models of handguns to be equipped with microstamping technology by 2010.

Several techniques have been proposed:
- Firearm microstamping is a process that engraves the make, model, and serial number on the cartridge and on the face of the firing pin, which stamps the primer as the firing pin impacts it.
- A British researcher\[6\] proposed in a 2008 report that ammunition manufacturers coat their bullets with pollen, or with a pollen deposit coated with a metal oxide. Pollen grains are sticky enough and have a sufficiently hard outer case to survive being fired. They also attach themselves to the clothing and hands of people who handle the ammunition and the gun, providing an additional forensics clue (the pollen is extremely difficult to wash off completely, according to the researchers). If manufacturers used unique pollen varieties or unique mixtures of pollen and oxide coatings, the manufacturing database could be used to quickly identify a bullet found at a crime scene, assuming the investigating bodies equip themselves with the necessary pollen-identification equipment.\[7\]
DNA profiling (also called DNA testing, DNA typing, or genetic fingerprinting) is a technique employed by forensic scientists to assist in the identification of individuals by their respective DNA profiles. DNA profiles are encrypted sets of numbers that reflect a person's DNA makeup, which can also be used as the person's identifier. DNA profiling should not be confused with full genome sequencing. DNA profiling uses repetitive ("repeat") sequences that are highly variable, called variable number tandem repeats (VNTR). VNTRs loci are very similar between closely related humans, but so variable that unrelated individuals are extremely unlikely to have the same VNTRs.

The DNA profiling technique was first reported in 1984 by Sir Alec Jeffreys at the University of Leicester in England, and is now the basis of several national DNA databases. Dr. Jeffreys's genetic fingerprinting was made commercially available in 1987, when a chemical company, ICI, started a blood-testing centre in England.

DNA profiling process

The process begins with a sample of an individual's DNA (typically called a "reference sample"). The most desirable method of collecting a reference sample is the use of a buccal swab, as this reduces the possibility of contamination. When this is not available (e.g. because a court order may be needed and not obtainable) other methods may need to be used to collect a sample of blood, saliva, semen, or other appropriate fluid or tissue from personal items (e.g. toothbrush, razor, etc.) or from stored samples (e.g. banked sperm or biopsy tissue). Samples obtained from blood relatives (biological relative) can provide an indication of an individual's profile, as could human remains which had been previously profiled.
A reference sample is then analyzed to create the individual's DNA profile using one of a number of techniques, discussed below. The DNA profile is then compared against another sample to determine whether there is a genetic match.

**RFLP analysis**

The first methods for finding out genetics used for DNA profiling involved restriction enzyme digestion, followed by Southern blot analysis. Although polymorphisms can exist in the restriction enzyme cleavage sites, more commonly the enzymes and DNA probes were used to analyze VNTR loci. However, the Southern blot technique is laborious, and requires large amounts of undegraded sample DNA. Also, Karl Brown's original technique looked at many minisatellite loci at the same time, increasing the observed variability, but making it hard to discern individual alleles (and thereby precluding parental testing). These early techniques have been supplanted by PCR-based assays.

**PCR analysis**

With the invention of the polymerase chain reaction (PCR) technique, DNA profiling took huge strides forward in both discriminating power and the ability to recover information from very small (or degraded) starting samples. PCR greatly amplifies the amounts of a specific region of DNA, using oligonucleotide primers and a thermostable DNA polymerase. Early assays such as the HLA-DQ alpha reverse dot blot strips grew to be very popular due to their ease of use, and the speed with which a result could be obtained. However they were not as discriminating as RFLP. It was also difficult to determine a DNA profile for mixed samples, such as a vaginal swab from a sexual assault victim.

Fortunately, the PCR method is readily adaptable for analyzing VNTR loci. In the United States the FBI has standardized a set of 13 VNTR assays for DNA typing, and has organized the CODIS database for forensic identification in criminal cases. Similar assays and databases have been set up in other countries. Also, commercial kits are available that analyze single-nucleotide polymorphisms (SNPs). These kits use PCR to amplify specific regions with known variations and hybridize them to probes anchored on cards, which results in a colored spot corresponding to the particular sequence variation.

**STR analysis**

The method of DNA profiling used today is based on PCR and uses short tandem repeats (STR). This method uses highly polymorphic regions that have short repeated sequences of DNA (the most common is 4 bases repeated, but there are other lengths in use, including 3 and 5 bases). Because unrelated people almost certainly have different numbers of repeat units, STRs can be used to discriminate between unrelated individuals. These STR loci (locations on a chromosome) are targeted with sequence-specific primers and amplified using PCR. The DNA fragments that result are then separated and detected using electrophoresis. There are two common methods of separation and detection, capillary electrophoresis (CE) and gel electrophoresis.
Each STR is polymorphic, however, the number of alleles is very small. Typically each STR allele will be shared by around 5 - 20% of individuals. The power of STR analysis comes from looking at multiple STR loci simultaneously. The pattern of alleles can identify an individual quite accurately. Thus STR analysis provides an excellent identification tool. The more STR regions that are tested in an individual the more discriminating the test becomes.

From country to country, different STR-based DNA-profiling systems are in use. In North America, systems which amplify the CODIS 13 core loci are almost universal, while in the UK the SGM+ system (which is compatible with The National DNA Database), is in use. Whichever system is used, many of the STR regions used are the same. These DNA-profiling systems are based on multiplex reactions, whereby many STR regions will be tested at the same time.

The true power of STR analysis is in its statistical power of discrimination. Because the 13 loci that are currently used for discrimination in CODIS are independently assorted (having a certain number of repeats at one locus doesn't change the likelihood of having any number of repeats at any other locus), the product rule for probabilities can be applied. This means that if someone has the DNA type of ABC, where the three loci were independent, we can say that the probability of having that DNA type is the probability of having type A times the probability of having type B times the probability of having type C. This has resulted in the ability to generate match probabilities of 1 in a quintillion (1 with 18 zeros after it) or more.

However, DNA database searches showed much more frequent than expected false DNA matches including one perfect 13 locus match out of only 30,000 DNA samples in Maryland in January 2007.[6] Moreover, since there are about 12 million monozygotic twins on Earth, that theoretical probability is useless. For example, the actual probability that 2 random people have the same DNA depends on whether there were twins or triplets (etc.) in the family, and the number of loci used in the test. Where twins are common, the probability of matching the DNA is 22 in 1000, or about 2.2 in 100 will have matching DNA.

In practice, the risk of contaminated-matching is much greater than matching a distant relative, such as a sample being contaminated from nearby objects, or from left-over cells transferred from a prior test. Logically, the risk is greater for matching the most common person in the samples: everything collected from, or in contact with, a victim is a major source of contamination for any other samples brought into a lab. For that reason, multiple control-samples are typically tested, to ensure that they stayed clean, when prepared during the same period as the actual test samples. Unexpected matches (or variations) in several control-samples indicates a high probability of contamination for the actual test samples. In a relationship test, the full DNA profiles should differ (except for twins), to prove that a person wasn't actually matched as being related to their own DNA in another sample.

**AmpFLP**

Another technique, AmpFLP, or amplified fragment length polymorphism was also put into practice during the early 1990s. This technique was also faster than RFLP analysis and used PCR to amplify DNA samples. It relied on variable number tandem repeat (VNTR) polymorphisms to distinguish various alleles, which were separated on a polyacrylamide gel using an allelic ladder (as opposed to a molecular weight ladder). Bands could be visualized by silver staining the gel. One popular locus for fingerprinting was the D1S80 locus. As with all PCR based methods, highly degraded DNA or very small amounts of DNA may cause allelic dropout (causing a mistake in thinking a heterozygote is a homozygote) or other stochastic effects. In addition, because the analysis is done on a gel, very high number repeats may bunch together at the top of the gel, making it difficult to resolve. AmpFLP analysis can be highly automated, and allows for easy creation of phylogenetic trees based on comparing individual samples of DNA. Due to its relatively low cost and ease of set-up and operation, AmpFLP remains popular in lower income countries.
DNA profiling

DNA family relationship analysis

Using PCR technology, DNA analysis is widely applied to determine genetic family relationships such as paternity, maternity, siblingship and other kinships.

During conception, the father’s sperm cell and the mother’s egg cell, each containing half the amount of DNA found in other body cells, meet and fuse to form a fertilized egg, called a zygote. The zygote contains a complete set of DNA molecules, a unique combination of DNA from both parents. This zygote divides and multiplies into an embryo and later, a full human being.

At each stage of development, all the cells forming the body contain the same DNA—half from the father and half from the mother. This fact allows the relationship testing to use all types of all samples including loose cells from the cheeks collected using buccal swabs, blood or other types of samples.

While a lot of DNA contains information for a certain function, there is some called junk DNA, which is currently used for human identification. At some special locations (called loci) in the junk DNA, predictable inheritance patterns were found to be useful in determining biological relationships. These locations contain specific DNA markers that DNA scientists use to identify individuals. In a routine DNA paternity test, the markers used are Short Tandem Repeats (STRs), short pieces of DNA that occur in highly differential repeat patterns among individuals.

Each person’s DNA contains two copies of these markers—one copy inherited from the father and one from the mother. Within a population, the markers at each person’s DNA location could differ in length and sometimes sequence, depending on the markers inherited from the parents.

The combination of marker sizes found in each person makes up his/her unique genetic profile. When determining the relationship between two individuals, their genetic profiles are compared to see if they share the same inheritance patterns at a statistically conclusive rate.

For example, the following sample report from this commercial DNA paternity testing laboratory Universal Genetics signifies how relatedness between parents and child is identified on those special markers:

<table>
<thead>
<tr>
<th>DNA Marker</th>
<th>Mother</th>
<th>Child</th>
<th>Alleged father</th>
</tr>
</thead>
<tbody>
<tr>
<td>D21S11</td>
<td>28, 30</td>
<td>28, 31</td>
<td>29, 31</td>
</tr>
<tr>
<td>D7S820</td>
<td>9, 10</td>
<td>10, 11</td>
<td>11, 12</td>
</tr>
<tr>
<td>TH01</td>
<td>14, 15</td>
<td>14, 16</td>
<td>15, 16</td>
</tr>
<tr>
<td>D13S317</td>
<td>7, 8</td>
<td>7, 9</td>
<td>8, 9</td>
</tr>
<tr>
<td>D19S433</td>
<td>14, 16.2</td>
<td>14, 15</td>
<td>15, 17</td>
</tr>
</tbody>
</table>

The partial results indicate that the child and the alleged father’s DNA match among these five markers. The complete test results show this correlation on 16 markers between the child and the tested man to draw a conclusion of whether or not the man is the biological father.

Scientifically, each marker is assigned with a Paternity Index (PI), which is a statistical measure of how powerfully a match at a particular marker indicates paternity. The PI of each marker is multiplied with each other to generate the Combined Paternity Index (CPI), which indicates the overall probability of an individual being the biological father of the tested child relative to any random man from the entire population of the same race. The CPI is then converted into a Probability of Paternity showing the degree of relatedness between the alleged father and child.

The DNA test report in other family relationship tests, such as grandparentage and siblingship tests, is similar to a paternity test report. Instead of the Combined Paternity Index, a different value, such as a Siblingship Index, is reported.

The report shows the genetic profiles of each tested person. If there are markers shared among the tested individuals, the probability of biological relationship is calculated to determine how likely the tested individuals share the same markers due to a blood relationship.
Y-chromosome analysis

Recent innovations have included the creation of primers targeting polymorphic regions on the Y-chromosome (Y-STR), which allows resolution of a mixed DNA sample from a male and female and/or cases in which a differential extraction is not possible. Y-chromosomes are paternally inherited, so Y-STR analysis can help in the identification of paternally related males. Y-STR analysis was performed in the Sally Hemings controversy to determine if Thomas Jefferson had sired a son with one of his slaves.

Mitochondrial analysis

For highly degraded samples, it is sometimes impossible to get a complete profile of the 13 CODIS STRs. In these situations, mitochondrial DNA (mtDNA) is sometimes typed due to there being many copies of mtDNA in a cell, while there may only be 1-2 copies of the nuclear DNA. Forensic scientists amplify the HV1 and HV2 regions of the mtDNA, then sequence each region and compare single-nucleotide differences to a reference. Because mtDNA is maternally inherited, directly linked maternal relatives can be used as match references, such as one's maternal grandmother's daughter's son. A difference of two or more nucleotides is generally considered to be an exclusion. Heteroplasmy and poly-C differences may throw off straight sequence comparisons, so some expertise on the part of the analyst is required. mtDNA is useful in determining clear identities, such as those of missing people when a maternally linked relative can be found. mtDNA testing was used in determining that Anna Anderson was not the Russian princess she had claimed to be, Anastasia Romanov.

mtDNA can be obtained from such material as hair shafts and old bones/teeth.

DNA databases

There are now several DNA databases in existence around the world. Some are private, but most of the largest databases are government controlled. The United States maintains the largest DNA database, with the Combined DNA Index System, holding over 5 million records as of 2007. The United Kingdom maintains the National DNA Database (NDNAD), which is of similar size, despite the UK's smaller population. The size of this database, and its rate of growth, is giving concern to civil liberties groups in the UK, where police have wide-ranging powers to take samples and retain them even in the event of acquittal.

The U.S. Patriot Act of the United States provides a means for the U.S. government to get DNA samples from other countries if they are either a division of, or head office of, a company operating in the U.S. Under the act, the American offices of the company can't divulge to their subsidiaries/offices in other countries the reasons that these DNA samples are sought or by whom.

When a match is made from a National DNA Databank to link a crime scene to an offender who has provided a DNA Sample to a databank that link is often referred to as a cold hit. A cold hit is of value in referring the police agency to a specific suspect but is of less evidential value than a DNA match made from outside the DNA Databank.

Considerations when evaluating DNA evidence

In the early days of the use of genetic fingerprinting as criminal evidence, juries were often swayed by spurious statistical arguments by defense lawyers along these lines: given a match that had a 1 in 5 million probability of occurring by chance, the lawyer would argue that this meant that in a country of say 60 million people there were 12 people who would also match the profile. This was then translated to a 1 in 12 chance of the suspect being the guilty one. This argument is not sound unless the suspect was drawn at random from the population of the country. In fact, a jury should consider how likely it is that an individual matching the genetic profile would also have been a suspect in the case for other reasons. Another spurious statistical argument is based on the false assumption that a 1 in 5 million probability of a match automatically translates into a 1 in 5 million probability of innocence and is known as
DNA profiling

the prosecutor's fallacy.

When using RFLP, the theoretical risk of a coincidental match is 1 in 100 billion (100,000,000,000), although the practical risk is actually 1 in 1000 because monozygotic twins are 0.2% of the human population. Moreover, the rate of laboratory error is almost certainly higher than this, and often actual laboratory procedures do not reflect the theory under which the coincidence probabilities were computed. For example, the coincidence probabilities may be calculated based on the probabilities that markers in two samples have bands in precisely the same location, but a laboratory worker may conclude that similar—but not precisely identical—band patterns result from identical genetic samples with some imperfection in the agarose gel. However, in this case, the laboratory worker increases the coincidence risk by expanding the criteria for declaring a match. Recent studies have quoted relatively high error rates which may be cause for concern. In the early days of genetic fingerprinting, the necessary population data to accurately compute a match probability was sometimes unavailable. Between 1992 and 1996, arbitrary low ceilings were controversially put on match probabilities used in RFLP analysis rather than the higher theoretically computed ones. Today, RFLP has become widely disused due to the advent of more discriminating, sensitive and easier technologies.

STRs do not suffer from such subjectivity and provide similar power of discrimination (1 in 10^13 for unrelated individuals if using a full SGM+ profile) It should be noted that figures of this magnitude are not considered to be statistically supportable by scientists in the UK, for unrelated individuals with full matching DNA profiles a match probability of 1 in a billion is considered statistically supportable (Since 1998 the DNA profiling system supported by The National DNA Database in the UK is the SGM+ DNA profiling system which includes 10 STR regions and a sex indicating test. However, with any DNA technique, the cautious juror should not convict on genetic fingerprint evidence alone if other factors raise doubt. Contamination with other evidence (secondary transfer) is a key source of incorrect DNA profiles and raising doubts as to whether a sample has been adulterated is a favorite defense technique. More rarely, chimerism is one such instance where the lack of a genetic match may unfairly exclude a suspect.

Evidence of genetic relationship

It's also possible to use DNA profiling as evidence of genetic relationship, but testing that shows no relationship is absolutely certain. While almost all individuals have a single and distinct set of genes, rare individuals, known as "chimeras", have at least two different sets of genes. There have been several cases of DNA profiling that falsely "proved" that a mother was unrelated to her children.

Fake DNA evidence

The value of DNA evidence has to be seen in light of recent cases where criminals planted fake DNA samples at crime scenes. In one case, a criminal even planted fake DNA evidence in his own body: Dr. John Schneeberger raped one of his sedated patients in 1992 and left semen on her underwear. Police drew what they believed to be Schneeberger's blood and compared its DNA against the crime scene semen DNA on three occasions, never showing a match. It turned out that he had surgically inserted a Penrose drain into his arm and filled it with foreign blood and anticoagulants.

In a study conducted by the life science company Nucleix and published in the journal Forensic Science International, scientists found that an In vitro synthesized sample of DNA matching any desired genetic profile can be constructed using standard molecular biology techniques without obtaining any actual tissue from that person. In the case of the Phantom of Heilbronn, police detectives found DNA traces from the same woman on various crime scenes in Austria, Germany and France - among them murders, burglaries and robberies. Only after the DNA of the "woman" matched the DNA sampled from the burned body of a male asylum seeker in France, detectives began to have serious doubts about the DNA evidence. In that case, DNA traces were already present on the cotton swabs used to collect the samples at the crime scene, and the swabs had all been produced at the same factory in Austria.
The company's product specification said that the swabs were guaranteed to be sterile, but not DNA-free.

**DNA evidence as evidence in criminal trials**

**Familial searching**

Familial searching is the use of family members' DNA to identify a closely related suspect in jurisdictions where large DNA databases exist, but no exact match has been found. The first successful use of the practice was in a UK case where a man was convicted of manslaughter when he threw a brick stained with his own blood into a moving car. Police could not get an exact match to the UK's DNA database because the man had no criminal convictions, but police implicated him using a close relative's DNA. The technique was used to catch a Los Angeles serial killer known as the "Grim Sleeper" in 2010.

**Surreptitious DNA collecting**

Police forces may collect DNA samples without the suspects' knowledge, and use it as evidence. Legality of this mode of proceeding has been questioned in Australia.

In the United States, it has been accepted, courts often claiming that there was no expectation of privacy, citing California v. Greenwood (1985), during which the Supreme Court held that the Fourth Amendment does not prohibit the warrantless search and seizure of garbage left for collection outside the curtilage of a home. Critics of this practice underline the fact that this analogy ignores that "most people have no idea that they risk surrendering their genetic identity to the police by, for instance, failing to destroy a used coffee cup. Moreover, even if they do realize it, there is no way to avoid abandoning one's DNA in public."

In the UK, the Human Tissue Act 2004 prohibited private individuals from covertly collecting biological samples (hair, fingernails, etc.) for DNA analysis, but excluded medical and criminal investigations from the offense.

**England and Wales**

Evidence from an expert who has compared DNA samples must be accompanied by evidence as to the sources of the samples and the procedures for obtaining the DNA profiles. The judge must ensure that the jury must understand the significance of DNA matches and mismatches in the profiles. The judge must also ensure that the jury does not confuse the 'match probability' (the probability that a person that is chosen at random has a matching DNA profile to the sample from the scene) with the 'likelihood ratio' (the probability that a person with matching DNA committed the crime). In *R v. Doheny* Phillips LJ gave this example of a summing up, which should be carefully tailored to the particular facts in each case:

> Members of the Jury, if you accept the scientific evidence called by the Crown, this indicates that there are probably only four or five white males in the United Kingdom from whom that semen stain could have come. The Defendant is one of them. If that is the position, the decision you have to reach, on all the evidence, is whether you are sure that it was the Defendant who left that stain or whether it is possible that it was one of that other small group of men who share the same DNA characteristics.

Juries should weigh up conflicting and corroborative evidence, using their own common sense and not by using mathematical formulae, such as Bayes' theorem, so as to avoid "confusion, misunderstanding and misjudgment."
Presentation and evaluation of evidence of partial or incomplete DNA profiles

In *R v Bates*[^20], Moore-Bick LJ said:

“We can see no reason why partial profile DNA evidence should not be admissible provided that the jury are made aware of its inherent limitations and are given a sufficient explanation to enable them to evaluate it. There may be cases where the match probability in relation to all the samples tested is so great that the judge would consider its probative value to be minimal and decide to exclude the evidence in the exercise of his discretion, but this gives rise to no new question of principle and can be left for decision on a case by case basis. However, the fact that there exists in the case of all partial profile evidence the possibility that a "missing" allele might exculpate the accused altogether does not provide sufficient grounds for rejecting such evidence. In many there is a possibility (at least in theory) that evidence exists which would assist the accused and perhaps even exculpate him altogether, but that does not provide grounds for excluding relevant evidence that is available and otherwise admissible, though it does make it important to ensure that the jury are given sufficient information to enable them to evaluate that evidence properly.”[^21]

DNA testing in the US

There are state laws on DNA profiling in all 50 states of the United States.[^22] Detailed information on database laws in each state can be found at the National Conference of State Legislatures website.[^23]

Development of artificial DNA

In August 2009, scientists in Israel raised serious doubts concerning the use of DNA by law enforcement as the ultimate method of identification. In a paper published in the journal *Forensic Science International: Genetics*, the Israeli researchers demonstrated that it is possible to manufacture DNA in a laboratory, thus falsifying DNA evidence. The scientists fabricated saliva and blood samples, which originally contained DNA from a person other than the supposed donor of the blood and saliva.[^24]

The researchers also showed that, using a DNA database, it is possible to take information from a profile and manufacture DNA to match it, and that this can be done without access to any actual DNA from the person whose DNA they are duplicating. The synthetic DNA oligos required for the procedure are common in molecular laboratories.[^24]

Dr. Daniel Frumkin, lead author on the paper, was quoted in *The New York Times* saying, "You can just engineer a crime scene... any biology undergraduate could perform this.”[^24]

Dr. Frumkin perfected a test that can differentiate real DNA samples from fake ones. His test detects epigenetic modifications, in particular, DNA methylation. Seventy percent of the DNA in any human genome is methylated, meaning it contains methyl group modifications within a CpG dinucleotide context. Methylation at the promoter region is associated with gene silencing. The synthetic DNA lacks this epigenetic modification, which allows the test to distinguish manufactured DNA from original, genuine, DNA.[^24]

It is unknown how many, if any, police departments currently use the test, which appears to be a serious issue. No police lab has publicly announced that it is using the new test to verify DNA results, even though any forensic laboratory doing DNA identification could adopt this test to authenticate its results as "real" DNA.[^25]
DNA profiling

Cases

• In the 1950s, Anna Anderson claimed that she was Grand Duchess Anastasia Nikolaevna of Russia. In the 1980's, after her death, samples of her tissue that had been stored at a Charlottesville, Virginia hospital following a medical procedure were tested using DNA fingerprinting, and showed that she bore no relation to the Romanovs.[26]

• In 1986, Richard Buckland was exonerated, despite having admitted to the rape and murder of a teenager near Leicester, the city where DNA profiling was first discovered. This was the first use of DNA fingerprinting in a criminal investigation.[27]

• In 1987, in the same case as Buckland, British baker Colin Pitchfork was the first criminal caught and convicted using DNA fingerprinting.[28]

• In 1987, genetic fingerprinting was used in criminal court for the first time in the trial of a man accused of unlawful intercourse with a mentally handicapped 14-year-old female who gave birth to his baby.[29]

• In 1987, Florida rapist Tommy Lee Andrews was the first person in the United States to be convicted as a result of DNA evidence, for raping a woman during a burglary; he was convicted on November 6, 1987, and sentenced to 22 years in prison.[30][31]

• In 1988, Timothy Wilson Spencer was the first man in Virginia to be sentenced to death through DNA testing, for several rape and murder charges. He was dubbed “The South Side Strangler” because he killed victims on the south side of Richmond, Virginia. He was later charged with rape and 1st degree murder and was sentenced to death. He was executed on April 27, 1994. David Vasquez, initially convicted of one of Spencer's crimes, became the first man in America exonerated based on DNA evidence.

• In 1989, Chicago man Gary Dotson was the first person whose conviction was overturned using DNA evidence.

• In 1991, Allan Legere was the first Canadian to be convicted as a result of DNA evidence, for four murders he had committed while an escaped prisoner in 1989. During his trial, his defense argued that the relatively shallow gene pool of the region could lead to false positives.

• In 1992, DNA evidence was used to prove that Nazi doctor Josef Mengele was buried in Brazil under the name Wolfgang Gerhard.

• In 1993, Kirk Bloodsworth was the first person to have been convicted of murder and sentenced to death, whose conviction was overturned using DNA evidence.

• The 1993 rape and murder of Mia Zapata, lead singer for the Seattle punk band The Gits was unsolved 9 years after the murder. A database search in 2001 failed, but the killer's DNA was collected when he was arrested in Florida for burglary and domestic abuse in 2002.

• The science was made famous in the United States in 1994 when prosecutors heavily relied on DNA evidence allegedly linking O.J. Simpson to a double murder. The case also brought to light the laboratory difficulties and handling procedure mishaps which can cause such evidence to be significantly doubted.

• In 1994, Royal Canadian Mounted Police (RCMP) detectives successfully tested hairs from a cat known as Snowball, and used the test to link a man to the murder of his wife, thus marking for the first time in forensic history the use of non-human DNA to identify a criminal.

• In 1998, Dr. Richard J. Schmidt was convicted of attempted second-degree murder when it was shown that there was a link between the viral DNA of the human immunodeficiency virus (HIV) he had been accused of injecting in his girlfriend and viral DNA from one of his patients with full-blown AIDS. This was the first time viral DNA fingerprinting had been used as evidence in a criminal trial.

• In 1999, Raymond Easton, a disabled man from Swindon, England, was arrested and detained for 7 hours in connection with a burglary. He was released due to an inaccurate DNA match. His DNA had been retained on file after an unrelated domestic incident some time previously.[32]

• In May 2000 Gordon Graham murdered Paul Gault at his home in Lisburn, Northern Ireland. Graham was convicted of the murder when his DNA was found on a sports bag left in the house as part of an elaborate ploy to
suggest the murder occurred after a burglary had gone wrong. Graham was having an affair with the victims wife at the time of the murder. It was the first time Low Copy Number DNA was used in Northern Ireland.[33]
• In 2001, Wayne Butler was convicted for the murder of Celia Douty. It was the first murder in Australia to be solved using DNA profiling.[34] [35]
• In 2002, DNA testing was used to exonerate Douglas Echols, a man who was wrongfully convicted in a 1986 rape case. Echols was the 114th person to be exonerated through post-conviction DNA testing.
• In August 2002, Annalisa Vincenzi was shot dead in Tuscany. Bartender Peter Hamkin, 23, was arrested, in Merseyside, in March 2003 on an extradition warrant heard at Bow Street Magistrates' Court in London to establish whether he should be taken to Italy to face a murder charge. DNA "proved" he shot her, but he was cleared on other evidence.[36]
• In 2003, Welshman Jeffrey Gafoor was convicted of the 1988 murder of Lynette White, when crime scene evidence collected 12 years earlier was re-examined using STR techniques, resulting in a match with his nephew.[37] This may be the first known example of the DNA of an innocent yet related individual being used to identify the actual criminal, via "familial searching".
• In June 2003, because of new DNA evidence, Dennis Halstead, John Kogut and John Restivo won a re-trial on their murder conviction. The three men had already served eighteen years of their thirty-plus-year sentences.
• The trial of Robert Pickton is notable in that DNA evidence is being used primarily to identify the victims, and in many cases to prove their existence.
• In March 2003, Josiah Sutton was released from prison after serving four years of a twelve-year sentence for a sexual assault charge. Questionable DNA samples taken from Sutton were retested in the wake of the Houston Police Department’s crime lab scandal of mishandling DNA evidence.
• In 2004, DNA testing shed new light into the mysterious 1912 disappearance of Bobby Dunbar, a four-year-old boy who vanished during a fishing trip. He was allegedly found alive eight months later in the custody of William Cantwell Walters, but another woman claimed that the boy was her son, Bruce Anderson, whom she had entrusted in Walters’ custody. The courts disbelieved her claim and convicted Walters for the kidnapping. The boy was raised and known as Bobby Dunbar throughout the rest of his life. However, DNA tests on Dunbar’s son and nephew revealed the two were not related, thus establishing that the boy found in 1912 was not Bobby Dunbar, whose real fate remains unknown.[38]
• In 2005, Gary Leiterman was convicted of the 1969 murder of Jane Mixer, a law student at the University of Michigan, after DNA found on Mixer's pantyhose was matched to Leiterman. DNA in a drop of blood on Mixer's hand was matched to John Ruelas, who was only four years old in 1969 and was never successfully connected to the case in any other way. Leiterman's defense unsuccessfully argued that the unexplained match of the blood spot to Ruelas pointed to cross-contamination and raised doubts about the reliability of the lab's identification of Leiterman.[39] [40] [41]
• In December 2005, Evan Simmons was proven innocent of a 1981 attack on an Atlanta woman after serving twenty-four years in prison. Mr Clark is the 164th person in the United States and the fifth in Georgia to be freed using post-conviction DNA testing.
• In March 2009, Sean Hodgson who spent 27 years in jail, convicted of killing Teresa De Simone, 22, in her car in Southampton 30 years ago was released by senior judges. Tests prove DNA from the scene was not his. British police have now reopened the case.
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[10] Nick Paton Walsh False result fear over DNA tests (http://www.guardian.co.uk/crime/article/0,2763,640157,00.html) The Observer, Sunday 27 January 2002


[26] Identification of the remains of the Romanov family by DNA analysis by Peter Gill, Central Research and Support Establishment, Forensic Science Service, Aldermaston, Reading, Berkshire, RG7 4PN, UK, Pavel L. Ivanov, Engelhardt Institute of Molecular Biology, Russian Academy of Sciences, 117984, Moscow, Russia, Colin Kimpton, Romelle Piercy, Nicola Benson, Gillian Tully, Ian Evett, Kevin Sullivan, Forensic Science Service, Priory House, Gooch Street North, Birmingham B5 6QQ, UK, Erika Hagleberg, University of Cambridge, Department of Biological Anthropology, Downing Street, Cambridge CB2 3DZ, UK - (http://www.nature.com/ng/journal/v6/n2/abs/ng0294-130.html)


External links

- DNA Fingerprinting (http://www.guardian.co.uk/science/2009/may/24/dna-fingerprinting-alec-jeffreys) Eureka Moment
- Create a DNA Fingerprint (http://www.pbs.org/wgbh/nova/sheppard/analyze.html) PBS.org
- In silico simulation of Molecular Biology Techniques (http://insilico.ehu.es) - A place to learn typing techniques by simulating them
- Fingerprinting.com (http://www.fingerprinting.com/dna-fingerprinting.php) DNA Fingerprinting Identification and Methods
Fingerprint

A **fingerprint** in its narrow sense is an impression left by the friction ridges of a human finger.\(^1\) In a wider use of the term, fingerprints are the traces of an impression from the friction ridges of any part of a human hand. A print from the foot can also leave an impression of friction ridges. A friction ridge is a raised portion of the epidermis on the fingers and toes (digits), the palm of the hand or the sole of the foot, consisting of one or more connected ridge units of friction ridge skin.\(^1\) These are sometimes known as "epidermal ridges" which are caused by the underlying interface between the dermal papillae of the dermis and the interpapillary (rete) pegs of the epidermis. These epidermal ridges serve to amplify vibrations triggered, for example, when fingertips brush across an uneven surface, better transmitting the signals to sensory nerves involved in fine texture perception.\(^2\) These ridges also assist in gripping rough surfaces, as well as smooth wet surfaces.\(^3\)

Impressions of fingerprints may be left behind on a surface by the natural secretions of sweat from the eccrine glands that are present in friction ridge skin, or they may be made by ink or other substances transferred from the peaks of friction ridges on the skin to a relatively smooth surface such as a fingerprint card.\(^4\) Fingerprint records normally contain impressions from the pad on the last joint of fingers and thumbs, although fingerprint cards also typically record portions of lower joint areas of the fingers.

**Fingerprints used for identification**

Fingerprint identification, known as **dactyloscopy**\(^5\) or hand print identification, is the process of comparing two instances of friction ridge skin impressions (see Minutiae), from human fingers, the palm of the hand or even toes, to determine whether these impressions could have come from the same individual. The flexibility of friction ridge skin means that no two finger or palm prints are ever exactly alike in every detail; even two impressions recorded immediately after each other from the same hand. Fingerprint identification, also referred to as individualization, involves an expert, or an expert computer system operating under threshold scoring rules, determining whether two friction ridge impressions are likely to have originated from the same finger or palm (or toe or sole).

An intentional recording of friction ridges is usually made with black printer's ink rolled across a contrasting white background, typically a white card. Friction ridges can also be recorded digitally using a technique called Live Scan. A "latent print" is the chance recording of friction ridges deposited on the surface of an object or a wall. Latent prints are invisible to the naked eye, whereas "patent prints" or "plastic prints" are viewable with the un-aided eye. Latent prints are often fragmentary and require chemical methods, powder, or alternative light sources in order to be made clear. Sometimes an ordinary bright flashlight will make a latent print visible.

When friction ridges come into contact with a surface that will take a print, material that is on the friction ridges such as perspiration, oil, grease, ink or blood, will be transferred to the surface. Factors which affect the quality of friction
ridge impressions are numerous. Pliability of the skin, deposition pressure, slippage, the material from which the surface is made, the roughness of the surface and the substance deposited are just some of the various factors which can cause a latent print to appear differently from any known recording of the same friction ridges. Indeed, the conditions surrounding every instance of friction ridge deposition are unique and never duplicated. For these reasons, fingerprint examiners are required to undergo extensive training.

**Fingerprint types**

**Exemplar prints**

Exemplar prints, or known prints, is the name given to fingerprints deliberately collected from a subject, whether for purposes of enrollment in a system or when under arrest for a suspected criminal offense. During criminal arrests, a set of exemplar prints will normally include one print taken from each finger that has been rolled from one edge of the nail to the other, plain (or slap) impressions of each of the four fingers of each hand, and plain impressions of each thumb. Exemplar prints can be collected using Live Scan or by using ink on paper cards.

**Latent prints**

Although the word latent means hidden or invisible, in modern usage for forensic science the term latent prints means any chance or accidental impression left by friction ridge skin on a surface, regardless of whether it is visible or invisible at the time of deposition. Electronic, chemical and physical processing techniques permit visualization of invisible latent print residues whether they are from natural sweat on the skin or from a contaminant such as motor oil, blood, ink, paint or some other form of dirt. The different types of fingerprint patterns, such as arch, loop and whorl, will be described below.

Latent prints may exhibit only a small portion of the surface of a finger and this may be smudged, distorted, overlapped by other prints from the same or from different individuals, or any or all of these in combination. For this reason, latent prints usually present an “inevitable source of error in making comparisons,” as they generally “contain less clarity, less content, and less undistorted information than a fingerprint taken under controlled conditions, and much, much less detail compared to the actual patterns of ridges and grooves of a finger.”

**Patent prints**

Patent prints are chance friction ridge impressions which are obvious to the human eye and which have been caused by the transfer of foreign material from a finger onto a surface. Some obvious examples would be impressions from flour and wet clay. Because they are already visible and have no need of enhancement they are generally photographed rather than being lifted in the way that latent prints are. An attempt to preserve the actual print is always made for later presentation in court, and there are many techniques used to do this. Patent prints can be left on a surface by materials such as ink, dirt, or blood.

**Plastic prints**

A plastic print is a friction ridge impression left in a material that retains the shape of the ridge detail. Although very few criminals would be careless enough to leave their prints in a lump of wet clay, this would make a perfect plastic print. Commonly encountered examples are melted candle wax, putty removed from the perimeter of window panes and thick grease deposits on car parts. Such prints are already visible and need no enhancement, but investigators must not overlook the potential that invisible latent prints deposited by accomplices may also be on such surfaces. After photographically recording such prints, attempts should be made to develop other non-plastic impressions deposited from sweat or other contaminates.
Electronic recording
There has been a newspaper report[8] of a man selling stolen watches sending images of them on a mobile phone, and those images included parts of his hands in enough detail for police to be able to identify fingerprint patterns.

Classifying fingerprints
Before computerisation replaced manual filing systems in large fingerprint operations, manual fingerprint classification systems were used to categorize fingerprints based on general ridge formations (such as the presence or absence of circular patterns on various fingers), thus permitting filing and retrieval of paper records in large collections based on friction ridge patterns alone. The most popular ten-print classification systems include the Roscher system, the Juan Vucetich system, and the Henry Classification System. Of these systems, the Roscher system was developed in Germany and implemented in both Germany and Japan, the Vucetich system (developed by a Croatian-born Buenos Aires Police Officer) was developed in Argentina and implemented throughout South America, and the Henry system was developed in India and implemented in most English-speaking countries.[9]

In the Henry system of classification, there are three basic fingerprint patterns: Loop, Whorl and Arch,[10] which constitute 60–65%, 30–35% and 5% of all fingerprints respectively.[11] There are also more complex classification systems that break down patterns even further, into plain arches or tented arches,[9] and into loops that may be radial or ulnar, depending on the side of the hand the tail points towards. Whorls may also have sub-group classifications including plain whorls, accidental whorls, double loop whorls, peacock's eye, composite, and central pocket loop whorls.[9]

The system used by most experts, although complex, is similar to the Henry System of Classification. It consists of five fractions, in which $R$ stands for right, $L$ for left, $i$ for index finger, $m$ for middle finger, $t$ for thumb, $r$ for ring finger and $p$ (pinky) for little finger. The fractions are as follows: $Ri/Rt + Rr/Rm + Lt/Rp + Lm/Li + Lp/Lr$. The numbers assigned to each print are based on whether or not they are whorls. A whorl in the first fraction is given a 16, the second an 8, the third a 4, the fourth a 2, and 0 to the last fraction. Arches and loops are assigned values of 0. Lastly, the numbers in the numerator and denominator are added up, using the scheme:

$$\frac{(Ri + Rr + Lt + Lm + Lp)/(Rt + Rm + Rp + Li + Lr)}{1}$$

and a 1 is added to both top and bottom, to exclude any possibility of division by zero. For example, if the right ring finger and the left index finger have whorls, the fractions would look like this:

$$0/0 + 8/0 + 0/2 + 0/0 + 1/1$$

and the calculation: $(0 + 8 + 0 + 0 + 0 + 1)/(0 + 0 + 0 + 2 + 0 + 1) = 9/3 = 3$.

Using this system reduces the number of prints that the print in question needs to be compared to. For example, the above set of prints would only need to be compared to other sets of fingerprints with a value of 3.[12]
Footprints

Friction ridge skin present on the soles of the feet and toes (plantar surfaces) is as unique in its ridge detail as are the fingers and palms (palmar surfaces). When recovered at crime scenes or on items of evidence, sole and toe impressions can be used in the same manner as finger and palm prints to effect identifications. Footprint (toe and sole friction ridge skin) evidence has been admitted in courts in the United States since 1934.[13]

The footprints of infants, along with the thumb or index finger prints of mothers, are still commonly recorded in hospitals to assist in verifying the identity of infants. Often, the only identifiable ridge detail that can be seen on a baby's foot is from the large toe or adjacent to the large toe.

It is not uncommon for military records of flight personnel to include bare foot inked impressions. Friction ridge skin protected inside flight boots tends to survive the trauma of a plane crash (and accompanying fire) better than fingers.
Even though the US Armed Forces DNA Identification Laboratory (AFDIL), as of 2010, stored refrigerated DNA samples from all active duty and reserve personnel, almost all casualty identifications are effected using fingerprints from military ID card records (live scan fingerprints are recorded at the time such cards are issued). When friction ridge skin is not available from deceased military personnel, DNA and dental records are used to confirm identity.

**Fingerprint capture and detection**

**Livescan devices**

Fingerprint image acquisition is considered to be the most critical step in an automated fingerprint authentication system, as it determines the final fingerprint image quality, which has a drastic effect on the overall system performance. There are different types of fingerprint readers on the market, but the basic idea behind each is to measure the physical difference between ridges and valleys.
All the proposed methods can be grouped into two major families: solid-state fingerprint readers and optical fingerprint readers. The procedure for capturing a fingerprint using a sensor consists of rolling or touching with the finger onto a sensing area, which according to the physical principle in use (optical, ultrasonic, capacitive or thermal) captures the difference between valleys and ridges. When a finger touches or rolls onto a surface, the elastic skin deforms. The quantity and direction of the pressure applied by the user, the skin conditions and the projection of an irregular 3D object (the finger) onto a 2D flat plane introduce distortions, noise and inconsistencies in the captured fingerprint image. These problems result in inconsistent, irreproducible and non-uniform irregularities in the image. During each acquisition, therefore, the results of the imaging are different and uncontrollable. The representation of the same fingerprint changes every time the finger is placed on the sensor plate, increasing the complexity of any attempt to match fingerprints, impairing the system performance and consequently, limiting the widespread use of this biometric technology.

In order to overcome these problems, as of 2010, non-contact or touchless 3D fingerprint scanners have been developed. Acquiring detailed 3D information, 3D fingerprint scanners take a digital approach to the cumbersome analog process of pressing or rolling the finger. By modelling the distance between neighboring points, the fingerprint can be imaged at a resolution high enough to record all the necessary detail.

Latent fingerprint detection
Since the late nineteenth century, fingerprint identification methods have been used by police agencies around the world to identify suspected criminals as well as the victims of crime. The basis of the traditional fingerprinting technique is simple. The skin on the palmar surface of the hands and feet forms ridges, so-called papillary ridges, in patterns that are unique to each individual and which do not change over time. Even identical twins (who share their DNA) do not have identical fingerprints. The best way to render latent fingerprints visible, so that they can be photographed, can be complex and may depend, for example, on the type of surfaces on which they have been left. It is generally necessary to use a 'developer', usually a powder or chemical reagent, to produce a high degree of visual contrast between the ridge patterns and the surface on which a fingerprint has been deposited.

Developing agents depend on the presence of organic materials or inorganic salts for their effectiveness, although the water deposited may also take a key role. Fingerprints are typically formed from the aqueous-based secretions of the eccrine glands of the fingers and palms with additional material from sebaceous glands primarily from the forehead. This latter contamination results from the common human behaviors of touching the face and hair. The resulting latent fingerprints consist usually of a substantial proportion of water with small traces of amino acids and chlorides.
mixed with a fatty, sebaceous component which contains a number of fatty acids and triglycerides. Detection of a small proportion of reactive organic substances such as urea and amino acids is far from easy.

Fingerprints at a crime scene may be detected by simple powders, or by chemicals applied *in situ*. More complex techniques, usually involving chemicals, can be applied in specialist laboratories to appropriate articles removed from a crime scene. With advances in these more sophisticated techniques, some of the more advanced crime scene investigation services from around the world were, as of 2010, reporting that 50% or more of the fingerprints recovered from a crime scene had been identified as a result of laboratory-based techniques.

**Laboratory techniques**

Although there are hundreds of reported techniques for fingerprint detection, many of these are only of academic interest and there are only around 20 really effective methods which are currently in use in the more advanced fingerprint laboratories around the world. Some of these techniques, such as ninhydrin, diazafluorenone and vacuum metal deposition, show great sensitivity and are used operationally. Some fingerprint reagents are specific, for example ninhydrin or diazafluorenone reacting with amino acids. Others such as ethyl cyanoacrylate polymerisation, work apparently by water-based catalysis and polymer growth. Vacuum metal deposition using gold and zinc has been shown to be non-specific, but can detect fat layers as thin as one molecule. More mundane methods, such as the application of fine powders, work by adhesion to sebaceous deposits and possibly aqueous deposits in the case of fresh fingerprints. The aqueous component of a fingerprint, whilst initially sometimes making up over 90% of the weight of the fingerprint, can evaporate quite quickly and may have mostly gone after 24 hours. Following work on the use of argon ion lasers for fingerprint detection, a wide range of fluorescence techniques have been introduced, primarily for the enhancement of chemically-developed fingerprints, although the inherent fluorescence of some latent fingerprints may also be detected. The most comprehensive manual of the operational methods of fingerprint enhancement is published by the UK Home Office Scientific Development Branch and is used widely around the world.

**Research**

The International Fingerprint Research Group (IFRG) which meets biennially, consists of members of the leading fingerprint research groups from Europe, the US, Canada, Australia and Israel and leads the way in the development, assessment and implementation of new techniques for operational fingerprint detection.

One problem for the early twenty-first century is the fact that the organic component of any deposited material is readily destroyed by heat, such as occurs when a gun is fired or a terrorist bomb is detonated, when the temperature may reach as high as 500°C. Encouragingly, however, the non-volatile inorganic component of eccrine secretion has been shown to remain intact even when exposed to temperatures as high as 600°C.

A technique has been developed that enables fingerprints to be visualised on metallic and electrically conductive surfaces without the need to develop the prints first. This technique involves the use of an instrument called a scanning Kelvin probe (SKP), which measures the voltage, or electrical potential, at pre-set intervals over the surface of an object on which a fingerprint may have been deposited. These measurements can then be mapped to produce an image of the fingerprint. A higher resolution image can be obtained by increasing the number of points sampled, but at the expense of the time taken for the process. A sampling frequency of 20 points per mm is high enough to visualise a fingerprint in sufficient detail for identification purposes and produces a voltage map in 2–3 hours. As of 2010, this technique had been shown to work effectively on a wide range of forensically important metal surfaces including iron, steel and aluminum. While initial experiments were performed on flat surfaces, the technique has been further developed to cope with irregular or curved surfaces, such as the warped cylindrical surface of fired cartridge cases. Research during 2010 at Swansea University has found that physically removing a fingerprint from a metal surface, for example by rubbing with a tissue, does not necessarily result in the loss of all fingerprint information from that surface. The reason for this is that the differences in potential that are the basis of the visualisation are caused by the interaction of inorganic salts in the fingerprint deposit and the metal surface and
Fingerprint

begin to occur as soon as the finger comes into contact with the metal, resulting in the formation of metal-ion complexes that cannot easily be removed.

Another problem for the early twenty-first century is that during crime scene investigations, a decision has to be made at an early stage whether to attempt to retrieve fingerprints through the use of developers or whether to swab surfaces in an attempt to salvage material for DNA profiling. The two processes are mutually incompatible, as fingerprint developers destroy material that could potentially be used for DNA analysis, and swabbing is likely to make fingerprint identification impossible.

The application of the new scanning Kelvin probe (SKP) fingerprinting technique, which makes no physical contact with the fingerprint and does not require the use of developers, has the potential to allow fingerprints to be recorded whilst still leaving intact material that could subsequently be subjected to DNA analysis. A forensically usable prototype was under development at Swansea University during 2010, in research that was generating significant interest from the British Home Office and a number of different police forces across the UK, as well as internationally. The hope is that this instrument could eventually be manufactured in sufficiently large numbers to be widely used by forensic teams worldwide.[22][23]

The disappearance of children's latent prints

In 1995, researchers at the Oak Ridge National Laboratory, at the instigation of Detective Art Bohanan of the Knoxville Police Department, discovered that children's fingerprints are considerably more short-lived than adult fingerprints.[5] The rapid disappearance of children's fingerprints was attributed to a lack of the more waxy oils that become present at the onset of puberty. The lighter fatty acids of children's fingerprints evaporate within a few hours. As of 2010, researchers at Oak Ridge National Laboratory are investigating techniques to capture these lost fingerprints.

Fingerprints reveal drug use

The secretions, skin oils and dead cells in a human fingerprint contain residues of various chemicals and their metabolites present in the body. These can be detected and used for forensic purposes. For example, the fingerprints of tobacco smokers contain traces of cotinine, a nicotine metabolite; they also contain traces of nicotine itself. Caution should be used, however, as its presence may be caused by mere contact of the finger with a tobacco product. By treating the fingerprint with gold nanoparticles with attached cotinine antibodies, and then subsequently with a fluorescent agent attached to cotinine antibodies, the fingerprint of a smoker becomes fluorescent; non-smokers' fingerprints stay dark. The same approach, as of 2010, is being tested for use in identifying heavy coffee drinkers, cannabis smokers, and users of various other drugs.[24][25] In 2008, British researchers developed methods of identifying users of marijuana, cocaine and methadone from their fingerprint residues.[26]
United States databases and compression

In the United States, the FBI manages a fingerprint identification system and database called the Integrated Automated Fingerprint Identification System, or IAFIS, which currently holds the fingerprints and criminal records of over 51 million criminal record subjects and over 1.5 million civil (non-criminal) fingerprint records. US Visit currently holds a repository of the fingerprints of over 50 million people, primarily in the form of two-finger records. In 2008, US Visit hoped to have changed over to a system recording FBI-standard ten-print records.

Most American law enforcement agencies use Wavelet Scalar Quantization (WSQ), a wavelet-based system for efficient storage of compressed fingerprint images at 500 pixels per inch (ppi). WSQ was developed by the FBI, the Los Alamos National Lab, and the National Institute for Standards and Technology (NIST). For fingerprints recorded at 1000 ppi spatial resolution, law enforcement (including the FBI) uses JPEG 2000 instead of WSQ.

History

Antiquity and the medieval period

Fingerprints have been found on ancient Babylonian clay tablets, seals, and pottery. They have also been found on the walls of Egyptian tombs and on Minoan, Greek, and Chinese pottery, as well as on bricks and tiles from ancient Babylon and Rome. Some of these fingerprints were deposited unintentionally by the potters and masons as a natural consequence of their work, and others were made in the process of adding decoration. However, on some pottery, fingerprints have been impressed so deeply into the clay that they were possibly intended to serve as an identifying mark by the maker.

Fingerprints were used as signatures in ancient Babylon in the second millennium BCE. In order to protect against forgery, parties to a legal contract would impress their fingerprints into a clay tablet on which the contract had been written. By 246 BCE, Chinese officials were impressing their fingerprints into the clay seals used to seal documents. With the advent of silk and paper in China, parties to a legal contract impressed their handprints on the document. Sometime before 851 CE, an Arab merchant in China, Abu Zayd Hasan, witnessed Chinese merchants using fingerprints to authenticate loans. By 702, Japan had adopted the Chinese practice of sealing contracts with fingerprints.

Although ancient peoples probably did not realize that fingerprints could uniquely identify individuals, references from the age of the Babylonian king Hammurabi (1792-1750 BCE) indicate that law officials would take the fingerprints of people who had been arrested. During China's Qin Dynasty, records have shown that officials took hand prints, foot prints as well as finger prints as evidence from a crime scene. In China, around 300 CE, handprints were used as evidence in a trial for theft. By 650, the Chinese historian Kia Kung-Yen remarked that fingerprints could be used as a means of authentication. In his Jami al-Tawarikh (Universal History), the Persian physician Rashid-al-Din Hamadani (also known as "Rashideddin", 1247–1318) refers to the Chinese practice of identifying people via their fingerprints, commenting: "Experience shows that no two individuals have fingers exactly alike." In Persia at this time, government documents may have been authenticated with thumbprints.
Europe in the 17th and 18th centuries

In 1684, the English physician, botanist, and microscopist Nehemiah Grew (1641–1712) published the first scientific paper to describe the ridge structure of the skin covering the fingers and palms. In 1685, the Dutch physician Govard Bidloo(1649–1713) and the Italian physician Marcello Malpighi(1628–1694) published books on anatomy which also illustrated the ridge structure of the fingers. A century later, in 1788, the German anatomist Johann Christoph Andreas Mayer (1747–1801) recognized that fingerprints are unique to each individual.

Modern era

Jan Evangelista Purkyně or Purkinje (1787–1869), a Czech physiologist and professor of anatomy at the University of Breslau, published a thesis in 1823 discussing 9 fingerprint patterns, but he did not mention any possibility of using fingerprints to identify people. Some years later, the German anatomist Georg von Meissner (1829–1905) studied friction ridges, and five years after this, in 1858, Sir William James Herschel initiated fingerprinting in India. In 1877 at Hooghly (near Calcutta) he instituted the use of fingerprints on contracts and deeds to prevent the then-rampant repudiation of signatures and he registered government pensioners' fingerprints to prevent the collection of money by relatives after a pensioner's death. Herschel also fingerprinted prisoners upon sentencing to prevent various frauds that were attempted in order to avoid serving a prison sentence.

In 1880, Dr Henry Faulds, a surgeon in a Tokyo hospital, published his first paper on the subject in the scientific journal Nature, discussing the usefulness of fingerprints for identification and proposing a method to record them with printing ink. He also established their first classification and was also the first to identify fingerprints left on a vial. Returning to the UK in 1886, he offered the concept to the Metropolitan Police in London but it was dismissed at that time. Faulds wrote to Charles Darwin with a description of his method but, too old and ill to work on it, Darwin gave the information to his cousin, Francis Galton, who was interested in anthropology. Galton, by 1892 Sir Francis Galton, having been thus inspired to study fingerprints for ten years, published a detailed statistical model of fingerprint analysis and identification and encouraged its use in forensic science in his book Finger Prints. He had calculated that the chance of a "false positive" (two different individuals having the same fingerprints) was about 1 in 64 billion.

Juan Vucetich, an Argentine chief police officer, created the first method of recording the fingerprints of individuals on file, associating these fingerprints to the anthropometric system of Alphonse Bertillon, who had created, in 1879, a system to identify individuals by anthropometric photographs and associated quantitative descriptions. A year later, in 1892, after studying Galton's pattern types, Vucetich set up the world's first fingerprint bureau. In that same year, Francisca Rojas of Necochea, was found in a house with neck injuries, whilst her two sons were found dead with their throats cut. Rojas accused a neighbour, but despite brutal interrogation, this neighbour would not confess to the crimes. Inspector Alvarez, a colleague of Vucetich, went to the scene and found a bloody thumb mark on a door. When it was compared with Rojas' prints, it was found to be identical with her right thumb. She then confessed to the murder of her sons.

A Fingerprint Bureau was established in Calcutta (Kolkata), India, in 1897, after the Council of the Governor General approved a committee report that fingerprints should be used for the classification of criminal records. Working in the Calcutta Anthropometric Bureau, before it became the Fingerprint Bureau, were Azizul Haque and Hem Chandra Bose. Haque and Bose were Indian fingerprint experts who have been credited with the primary development of a fingerprint classification system eventually named after their supervisor, Sir Edward Richard Henry. The Henry Classification System, co-devised by Haque and Bose, was accepted in England and Wales when the first United Kingdom Fingerprint Bureau was founded in Scotland Yard, the Metropolitan Police headquarters, London, in 1901. Sir Edward Richard Henry subsequently achieved improvements in dactyloscopy.

In the United States, Dr Henry P. DeForrest used fingerprinting in the New York Civil Service in 1902, and by 1906, New York City Police Department Deputy Commissioner Joseph A. Faurot, an expert in the Bertillon system and a fingerprint advocate at Police Headquarters, introduced the fingerprinting of criminals to the United States.
The Scheffer case of 1902 is the first case of the identification, arrest and conviction of a murderer based upon fingerprint evidence. Alphonse Bertillon identified the thief and murderer Scheffer, who had previously been arrested and his fingerprints filed some months before, from the fingerprints found on a fractured glass showcase, after a theft in a dentist's apartment where the dentist's employee was found dead. It was able to be proved in Court that the fingerprints had been made after the showcase was broken. A year later, Alphonse Bertillon created a method of getting fingerprints off smooth surfaces and took a further step in the advance of dactyloscopy.

Validity of fingerprinting for identification

The validity of forensic fingerprint evidence has been challenged by academics, judges and the media. While fingerprint identification was an improvement on earlier anthropometric systems, the subjective nature of matching, despite a very low error rate, has made this forensic practice controversial.

Certain specific criticisms are now being accepted by some leaders of the forensic fingerprint community, providing an incentive to improve training and procedures.

Criticism

The words "reliability" and "validity" have specific meanings to the scientific community. Reliability means that successive tests bring the same results. Validity means that these results are judged to accurately reflect the external criteria being measured.

"Although experts are often more comfortable relying on their instincts, this reliance does not always translate into superior predictive ability. For example, in the popular Analysis, Comparison, Evaluation, and Verification (ACE-V) paradigm for fingerprint identification, the verification stage, in which a second examiner confirms the assessment of the original examiner, may increase the consistency of the assessments. But while the verification stage has implications for the reliability of latent print comparisons, it does not assure their validity."
—Sandy L Zabell, 2005.

The few tests that have been made of the validity of forensic fingerprinting have not been supportive of the method.

"Despite the absence of objective standards, scientific validation, and adequate statistical studies, a natural question to ask is how well fingerprint examiners actually perform. Proficiency tests do not validate a procedure per se, but they can provide some insight into error rates. In 1995, the Collaborative Testing Service (CTS) administered a proficiency test that, for the first time, was "designed, assembled, and reviewed" by the International Association for Identification (IAI). The results were disappointing. Four suspect cards with prints of all ten fingers were provided together with seven latents. Of 156 people taking the test, only 68 (44%) correctly classified all seven latents. Overall, the tests contained a total of 48 incorrect identifications. David Grieve, the editor of the Journal of Forensic Identification, describes the reaction of the forensic community to the results of the CTS test as ranging from "shock to disbelief," and added:

'The errors of this magnitude within a discipline singularly admired and respected for its touted absolute certainty as an identification process have produced chilling and mind-numbing realities. Thirty-four participants, an incredible 22% of those involved, substituted presumed but false certainty for truth. By any measure, this represents a profile of practice that is unacceptable and thus demands positive action by the entire community.'

What is striking about these comments is that they do not come from a critic of the fingerprint community, but from the editor of one of its premier publications."
—Sandy L Zabell, 2005.

Investigations have been conducted into whether experts can objectively focus on feature information in fingerprints without being misled by extraneous information, such as context. Fingerprints that have previously been
examined and assessed by latent print experts to make a positive identification of suspects have then been re-presented to those same experts in a new context which makes it likely that there will be no match. Within this new context, most of the fingerprint experts made different judgments, thus contradicting their own previous identification decisions.  

Complaints have been made that there have been no published, peer-reviewed studies directly examining the extent to which people can correctly match fingerprints to one another. Experiments have been carried out using naïve undergraduates to match images of fingerprints. The results of these experiments demonstrate that people can identify fingerprints quite well, and that matching accuracy can vary as a function of both source finger type and image similarity.

Defense

Fingerprints collected at a crime scene, or on items of evidence from a crime, have been used in forensic science to identify suspects, victims and other persons who touched a surface. Fingerprint identification emerged as an important system within police agencies in the late 19th century, when it replaced anthropometric measurements as a more reliable method for identifying persons having a prior record, often under a false name, in a criminal record repository. The science of fingerprint identification has been able to assert its standing amongst forensic sciences for many reasons.

Track record

Fingerprinting has served all governments worldwide during the past 100 years or so to provide accurate identification of criminals. No two fingerprints have ever been found identical in many billions of human and automated computer comparisons. Fingerprints are the fundamental tool for the identification of people with a criminal history in every police agency. It remains the most commonly gathered forensic evidence worldwide and in most jurisdictions fingerprint examination outnumbers all other forensic examination casework combined. Moreover, it continues to expand as the premier method for identifying persons, with tens of thousands of people added to fingerprint repositories daily in America alone – far more than other forensic databases. It is claimed to outperform DNA and all other human identification systems. Fingerprints solve ten times more unknown suspect cases than DNA in most police departments.

Professional standing and certification

Fingerprinting was the basis upon which the first forensic professional organization was formed, the International Association for Identification (IAI), in 1915. The first professional certification program for forensic scientists was established in 1977, the IAI's Certified Latent Print Examiner program, which issued certificates to those meeting stringent criteria and had the power to revoke certification where an individual's performance warranted it. Other forensic disciplines have followed suit and established their own certification programs.

Instances of error

Brandon Mayfield and the Madrid bombing

Brandon Mayfield is an Oregon lawyer who was identified as a participant in the Madrid bombing based on a fingerprint match by the FBI. The FBI Latent Print Unit processed a fingerprint collected in Madrid and reported a "100 percent positive" match against one of the 20 fingerprint candidates returned in a search response from their IAFIS — Integrated Automated Fingerprint Identification System. The FBI initially called it an "absolutely incontrovertible match". Subsequently, however, Spanish National Police examiners suggested that the print did not match Mayfield and after two weeks, identified another man whom they claimed the fingerprint did belong to. The FBI acknowledged their error, and a judge released Mayfield, who had spent two weeks in police custody, in May 2004. In January 2006, a U.S. Justice Department report was released which criticized the FBI for sloppy work
but exonerated them of some more serious allegations. The report found that the misidentification had been due to a misapplication of methodology by the examiners involved: Mayfield is an American-born convert to Islam and his wife is an Egyptian immigrant, but these are not factors that should have affected fingerprint search technology.

On 29 November 2006, the FBI agreed to pay Brandon Mayfield the sum of US$2 million in compensation. The judicial settlement allowed Mayfield to continue a suit regarding certain other government practices surrounding his arrest and detention. The formal apology stated that the FBI, which erroneously linked him to the 2004 Madrid bombing through a fingerprinting mistake, had taken steps to "ensure that what happened to Mr Mayfield and the Mayfield family does not happen again."

**René Ramón Sánchez**

René Ramón Sánchez, a legal Dominican Republic immigrant to the US was arrested on July 15, 1995, on a charge of driving while intoxicated (Driving Under the Influence, or DUI). His fingerprints, however, were placed on a card containing the name, Social Security number and other data for one Leo Rosario, who was being processed at the same time. Leo Rosario had been arrested for selling cocaine to an undercover police officer. On October 11, 2000, while returning from a visit to relatives in the Dominican Republic, René was mis-identified as Leo Rosario at John F. Kennedy International Airport in New York and arrested. Even though he did not match the physical description of Rosario, the erroneously-cataloged fingerprints were considered to be more reliable.

**Shirley McKie**

Shirley McKie was a police detective in 1997 when she was accused of leaving her thumb print inside a house in Kilmarnock, Scotland where Marion Ross had been murdered. Although McKie denied having been inside the house, she was arrested in a dawn raid the following year and charged with perjury. The only evidence the prosecution had was this thumb print allegedly found at the murder scene. Two American experts testified on her behalf at her trial in May 1999 and she was found not guilty. The Scottish Criminal Record Office (SCRO) would not admit any error, however, although Scottish first minister Jack McConnell later said it had been an "honest mistake".

On February 7, 2006, McKie was awarded £750,000 in compensation from the Scottish Executive and the Scottish Criminal Record Office. Controversy continued to surround the McKie case and there was an ongoing public inquiry into the affair, as of November 2009.

**Stephan Cowans**

Stephan Cowans was convicted of attempted murder in 1997 after he was accused of the shooting of a police officer whilst fleeing a robbery in Roxbury, Massachusetts. He was implicated in the crime by the testimony of two witnesses, one of whom was the victim. There was also a fingerprint on a glass mug from which the assailant had drunk some water and experts testified that the fingerprint belonged to Cowans. He was found guilty and sent to prison for 35 years. Whilst in prison, Cowans earned money cleaning up biohazards until he could afford to have the evidence against him tested for DNA. The DNA did not match his and he was released. He had already served six years in prison.

Stephen Cowans died on October 25, 2007.
Privacy issues

Fingerprinting of children

Various schools have implemented fingerprint locks or made a record of children's fingerprints. In the United Kingdom there have been fingerprint locks in Holland Park School in London,[65] and children's fingerprints are stored on databases.[66] There have also been instances in Belgium, at the école Marie-José in Liège,[67][68] in France and in Italy. The non-governmental organization (NGO) Privacy International in 2002 made the cautionary announcement that tens of thousands of UK school children were being fingerprinted by schools, often without the knowledge or consent of their parents.[69] That same year, the supplier Micro Librarian Systems, which uses a technology similar to that used in US prisons and the German military, estimated that 350 schools throughout Britain were using such systems, to replace library cards.[69] By 2007, it was estimated that 3,500 schools were using such systems.[70] Under the United Kingdom Data Protection Act, schools in the UK do not have to ask parental consent to allow such practices to take place. Parents opposed to fingerprinting may only bring individual complaints against schools.[71] In response to a complaint which they are continuing to pursue, in 2010 the European Commission expressed 'significant concerns' over the proportionality and necessity of the practice and the lack of judicial redress, indicating that the practice may break the European Union data protection directive.[72]

In Belgium, the practice of taking fingerprints from children gave rise to a question in Parliament on February 6, 2007 by Michel de La Motte (Humanist Democratic Centre) to the Education Minister Marie Arena, who replied that it was legal provided that the school did not use them for external purposes, or to survey the private life of children.[73] At Angers in France, Carqueiranne College in the Var won the Big Brother Award for 2005 and the Commission nationale de l'informatique et des libertés (CNIL), the official organisation in charge of the protection of privacy in France, declared the measures it had introduced "disproportionate."[74]

In March 2007, the British government was considering fingerprinting all children aged 11 to 15 as part of a new passport and ID card scheme and disallowing opposition for privacy concerns. All fingerprints taken would be cross-checked against prints from 900,000 unsolved crimes. Shadow Home secretary David Davis called the plan "sinister".[70] An Early Day Motion which called on the UK Government to conduct a full and open consultation with stakeholders about the use of biometrics in schools, secured the support of 85 Members of Parliament (Early Day Motion 686).[75] Following the establishment in the United Kingdom of a Conservative and Liberal Democratic coalition government in May 2010, the ID card scheme was scrapped.[76]

Serious concerns about the security implications of using conventional biometric templates in schools have been raised by a number of leading IT security experts,[77] one of whom has voiced the opinion that "it is absolutely premature to begin using 'conventional biometrics' in schools".[78] The vendors of Biometric systems claim that their products bring benefits to schools such as improved reading skills, decreased wait times in lunch lines and increased revenues.[79] They do not cite independent research to support this view. One education specialist wrote in 2007: "I have not been able to find a single piece of published research which suggests that the use of biometrics in schools promotes healthy eating or improves reading skills amongst children... There is absolutely no evidence for such claims."[80] The Ottawa Police in Canada have had to give advise to parents who fear that their children may be kidnapped to have their fingerprints taken.[81]
Other uses

Welfare claimants

It has been alleged that taking the fingerprints of welfare recipients as identification serves as a social stigma that evokes cultural images associated with the processing of criminals.\[82\]

Log-in authentication and other locks

Since 2000, electronic fingerprint readers have been introduced for security applications such as log-in authentication for the identification of computer users. However, some less sophisticated devices have been discovered to be vulnerable to quite simple methods of deception, such as fake fingerprints cast in gels. In 2006, fingerprint sensors gained popularity in the notebook PC market. Built-in sensors in ThinkPads, VAIO, HP Pavilion laptops, and others also double as motion detectors for document scrolling, like the scroll wheel.

Electronic registration and library access

Fingerprints and, to a lesser extent, iris scans can be used to validate electronic registration, cashless catering, and library access. By 2007, this practice was particularly widespread in UK schools,\[83\] and it was also starting to be adopted in some states in the US.

Fingerprints in other species

Some other animals have evolved their own unique prints, especially those whose lifestyle involves climbing or grasping wet objects; these include many primates, such as gorillas and chimpanzees, Australian koalas and aquatic mammal species such as the North American fisher.\[84\] According to one study, even with an electron microscope, it can be quite difficult to distinguish between the fingerprints of a koala and a human.\[85\]

Fingerprints in fiction

Mark Twain

Mark Twain's novel *Life on the Mississippi*, published in 1883, was the first book to use fingerprints as a main plot element.\[86\] Twain's later book *Pudd'nhead Wilson*, published in 1893, includes a courtroom drama involving fingerprint identification.

Crime fiction

The use of fingerprints in crime fiction has, of course, kept pace with its use in real-life detection. Sir Arthur Conan Doyle wrote a short story about his celebrated sleuth Sherlock Holmes which features a fingerprint: *The Norwood Builder* is a 1903 Sherlock Holmes short story set in 1894 and involves the discovery of a bloody fingerprint which helps Holmes to expose the real criminal and free his client. A 1985 Granada TV adaptation of an 1893 Sherlock Holmes short story set in 1891, *The Adventure of the Final Problem*, has a plot hole in the screenplay caused by Holmes's use of the Bertillon criminal ID system, in which he uses fingerprints to trap Moriarty's agents and recover the Mona Lisa. The real Bertillon system did not use fingerprints. Bertillon had added four spaces for fingerprints on his identification cards by 1900 because of the growing popularity of fingerprinting, but the identification cards were still based on anthropometric measurements.

The British detective writer R. Austin Freeman's first Thorndyke novel *The Red Thumb-Mark* was published in 1907 and features a bloody fingerprint left on a piece of paper together with a parcel of diamonds inside a safe-box. These become the center of a medico-legal investigation led by Dr Thorndyke, who defends the accused whose fingerprint matches that on the paper, after the diamonds are stolen.
Movies
The movie *Men In Black*, a popular 1997 science fiction thriller, required Agent J, played by Will Smith, to remove his ten fingerprints by putting his hands on a metal ball, an action deemed necessary by the MIB agency to remove the identity of its agents. And in a 2009 science fiction movie starring Paul Giamatti, *Cold Souls*, a mule who is paid to smuggle souls across borders, wears latex fingerprints to frustrate airport security terminals. She can change her identity by changing her wig, and switching latex fingerprints from the privacy of a restroom, always storing extra fingerprints in a ziploc bag, so she can always assume an alias that is suitable to her undertaking.

Other reliable identifiers
Other forms of biometric identification utilizing a physical attribute that is unique to every human include Iris recognition, the use of dental records in forensic dentistry, the tongue and DNA profiling, also known as genetic fingerprinting.

Fingerprint mutilation
There are several documented cases of people deliberately mutilating their fingerprints in an effort to avoid being identified from marks left on the surfaces they touch. Methods used have included burning the fingertips with acid, which John Dillinger tried (and failed; prints taken during a previous arrest and upon death still exhibited almost complete relation to one another), and surgical alteration.  

References
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[70] Child fingerprint plan considered (http://news.bbc.co.uk/1/hi/uk/6417565.stm), BBC, March 4, 2007 (English)

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[73] Prises d'empreintes digitales dans un établissement scolaire (http://www.ledchb.de/docparlement/pa4896.htm), Question d'actualité à la Ministre-Présidente en charge de l'Enseignement obligatoire et de Promotion sociale (French)

[74] Quand la biométrie s'installe dans les cantines au nez et à la barbe de la Cnil (http://www.zdnet.fr/actualites/informatique/0,39040745,39122509,00.htm), Zdnet, September 9, 2003 (French)


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Further reading


External links

General

- FBI Fingerprinting Video Lesson ([http://www.fbi.gov/hq/cjisd/fproll.html](http://www.fbi.gov/hq/cjisd/fproll.html)) (4-sec Quicktime video of rolling a single inked finger)
- Fingerprinting.com ([http://www.fingerprinting.com](http://www.fingerprinting.com))
- Henry, Faulds, and Herschel's works on fingerprints ([http://www.mugu.com/galton/fingerprints/books/index.htm](http://www.mugu.com/galton/fingerprints/books/index.htm))

Errors and concerns

- Will West as fable ([http://www.scafo.org/library/110105.html](http://www.scafo.org/library/110105.html))
Forensic footwear evidence

Forensic footwear evidence can be used in legal proceedings to help prove the identities of persons at the crime scene. Footwear evidence is often the most abundant form of evidence at a crime scene and in some cases can prove to be as specific as a fingerprint. Initially investigators will look to identify the make and model of the shoe or trainer which made an impression. This can be done visually or by comparison with evidence in a database both methods focus heavily on pattern recognition and brand or logo marks. Information about the owner of any footwear can be gained from the analysis of wear patterns which are dependent on angle of footfall and weight distribution. Detailed examination of footwear impressions can help to link a specific piece of footwear to a footwear imprint as each shoe will have unique wear characteristics.

Types of footwear evidence

Footwear evidence can come in at least three forms, footwear outsole impressions, footwear insole impressions and footwear trace evidence.

Footwear outsole impressions

Footwear outsole impressions are impressions left on an object that was caused by contact with a piece of footwear. These can left on the ground or raised surface by persons treading over it, left on doors or walls by persons attempting to kick or climb over a wall or even left on other persons after being kicked or stomped on. There can also be latent impressions not easily visible to the naked eye, on many different surfaces such as floor tiles, concrete or even carpet. Detection may require the use of additional specialized light sources such as portable ultraviolet lighting. Recovery typically includes photography as well as lifting with "gel” or "electrostatic” dust lifters.

Footwear insole imprints

Footwear insole imprints are imprints left in the inside of footwear caused by contact from the person's foot. Analysis of the insole imprints can be used to link a person(s) to a piece of footwear.

Footwear trace evidence

Footwear trace evidence is trace evidence that is recovered from footwear. Types of trace evidence that could be recovered include skin, glass fragments, body hair, fibres from clothing or carpets, soil particles, dust and bodily fluids. The study of this trace evidence could be used to link a piece of footwear to a location or owner. DNA can be one of the contributing factors in forensic footwear evidence.
Detection of footwear evidence

Footwear impressions can be detected with a variety of methods including:

- Using artificial light sources to provide oblique, coaxial, and polarized light for detection of visible and latent impressions.
- Using electrostatic lifting devices to lift dusty impressions.
- Using physical or chemical enhancement methods to develop or enhance faint impressions.

Recovery of footwear impression evidence

Footwear evidence occurs most often as either footwear impressions left in a soft surface, such as mud or as dust deposits, which are difficult for the human eye to detect. At violent crime scenes footmarks can be left as a result of a person standing in blood and subsequently trailing it as they move around the scene.

Lifting

Footwear impressions can be lifted from surfaces with tools such as adhesive lifters, gelatin lifters or electrostatic lifting devices.

Casting

Evidence left via impressions can generally be recovered utilizing a plaster cast. Initially the impression is isolated by framing the area with a solid boundary. Following this a plaster mix can be gently poured inside the frame, it is generally considered not best practice to pour directly onto the impression. In some cases where the surface is not ideal for casting prior techniques can be utilised to gain a better cast of the impression. Sand can often be fixed in place by applying an aerosol resin or glue although hair spray is often used. Wet mud impressions can be dried using a combination of pipetting water from the surface and applying hot air, often in the form of a hair dryer.

Examination of footwear impressions evidence

Footwear impression can be used by examiners to obtain information the following information:

**Footwear manufacturer, model and size:** Examination of footwear impression for "Class Characteristics" such as general outsole patterns and shapes, footwear design features and feature markings can help examiners identify the manufacturer, model and size of the footwear. This information can be used to help profile the suspect and provide leads on who may have bought or worn the footwear which created the impression.

**Approximate height and wearer:** Measurements of footwear impression dimensions can be used to provide the approximate height of a suspect. With shoeprint size information, investigators can refer to statistical data to approximate the height of the person since shoeprint vs. height relationship follows a normal distribution. Height can also be approximate by stride length which could be measured from a set of footwear impressions.

**Activity of wearer when imprint was made:** Analysis of a plastic footwear impression can also be used help determine the activity of the wearing when the imprint was made. The footwear imprint left by person is different when they are walking, running or carry heavy loads. A footwear impression left by running person will typically deeper in the heel and toe sections of the shoeprint. A person carrying a heavy load such as a body will cause deeper prints than a person not carrying anything.

**Establish link between footwear impression and specific piece of footwear:** A specific piece of footwear can be
linked to a specific footwear impression with careful analysis. Every piece of footwear will show different amounts of tread wear, different amounts of damage in the form of tiny cuts and nicks. These unique characteristics will also show on the impression left by the footwear.

Limitations of footwear evidence

The Unabomber, Theodore Kaczynski, was known to keep shoes with smaller soles attached to the base in order to confuse investigators about the size of the suspect's feet.\[1\]

Footwear databases

Forensic investigators can use computerized footwear databases to quickly compare the class characteristics between footwear impression and outsole profile of footwear outsoles stored in the database. This greatly reduced the time required to match shoemarks found at crime scenes and those from criminals in custody or those stored on the database.

By far the best system available is SICAR, marketed by Foster + Freeman Ltd, Worcestershire, England and currently used by Police departments in the UK, Europe, and USA. Others are available such as the Footwear Intelligence Technology (FIT) launched by the Forensic Science Service (FSS) in February 2007 and TreadMark.

References

Fox News. 2006-11-29.  “To evade authorities chasing him, Unabomber Theodore Kaczynski kept shoes with smaller soles attached to the bottom in his reclusive Montana cabin, according to evidence released 10 years after his capture”

External links

• Scientific Working Group on Shoeprint and Tire Tread Evidence (SWGTTRED) (http://www.theiai.org/guidelines/swgtread/index.php/), from the International Association for Identification
Forensic toxicology

Forensic toxicology is the use of toxicology and other disciplines such as analytical chemistry, pharmacology and clinical chemistry to aid medical or legal investigation of death, poisoning, and drug use. The primary concern for forensic toxicology is not the legal outcome of the toxicological investigation or the technology utilised, but rather the obtaining and interpreting of the results. A toxicological analysis can be done to various kinds of samples.

A forensic toxicologist must consider the context of an investigation, in particular any physical symptoms recorded, and any evidence collected at a crime scene that may narrow the search, such as pill bottles, powders, trace residue, and any available chemicals. Provided with this information and samples with which to work, the forensic toxicologist must determine which toxic substances are present, in what concentrations, and the probable effect of those chemicals on the person.

Determining the substance ingested is often complicated by the body's natural processes (see ADME), as it is rare for a chemical to remain in its original form once in the body. For example: heroin is almost immediately metabolised into another substance and further to morphine, making detailed investigation into factors such as injection marks and chemical purity necessary to confirm diagnosis. The substance may also have been diluted by its dispersal through the body; while a pill or other regulated dose of a drug may have grams or milligrams of the active constituent, an individual sample under investigation may only contain micrograms or nanograms.

Samples

Urine

A urine sample is urine that has come from the bladder and can be provided or taken post-mortem.

Blood

A blood sample of approximately 10 ml (0.35 imp fl oz; 0.34 US fl oz) is usually sufficient to screen and confirm most common toxic substances. A blood sample provides the toxicologist with a profile of the substance that the subject was influenced by at the time of collection; for this reason, it is the sample of choice for measuring blood alcohol content in drunk driving cases.

Hair sample

Hair is capable of recording medium to long-term or high dosage substance abuse. Chemicals in the bloodstream may be transferred to the growing hair and stored in the follicle, providing a rough timeline of drug intake events. Head hair grows at rate of approximately 1 to 1.5 cm a month, and so cross sections from different sections of the follicle can give estimates as to when a substance was ingested. Testing for drugs in hair is not standard throughout the population. The darker and coarser the hair the more drug that will be found in the hair. If two people consumed the same amount of drugs, the person with the lighter and coarser hair will have more drug in their hair than the darker haired person when tested. This raises issues of possible racial bias in substance tests with hair samples. [1]

Oral fluid

Oral fluid is the proper term, however saliva is used commonly. Saliva is a component of oral fluid. Oral fluid is composed of many things and concentrations of drugs typically parallel to those found in blood. Sometimes referred to as ultra filtrate of blood, it is thought that drugs pass into oral fluid predominantly through a process known as passive diffusion. Drugs and pharmaceuticals that are highly protein bound in blood will have a lower concentration in oral fluid. The use of oral fluid is gaining importance in forensic toxicology for showing recent drug use, e.g. in clinical settings or investigation of driving under influence of substances.
Other

Other bodily fluids and organs may provide samples, particularly samples collected during an autopsy. A common autopsy sample is the gastric contents of the deceased, which can be useful for detecting undigested pills or liquids that were ingested prior to death. In highly decomposed bodies, traditional samples may no longer be available. The vitreous humour from the eye may be used, as the fibrous layer of the eyeball and the eye socket of the skull protects the sample from trauma and adulteration. Other common organs used for toxicology are the brain, liver, and spleen. The inspection of the contents of the stomach must be part of every postmortem examination if possible because it may provide qualitative information concerning the nature of the last meal and the presence of abnormal constituents. Using it as a guide to the time of death, however, is theoretically unsound and presents many practical difficulties, although it may have limited applicability in some exceptional instances. Generally, using stomach contents as a guide to time of death involves an unacceptable degree of imprecision and is thus liable to mislead the investigator and the court. Characteristic cell types from food plants can be used to identify a victim's last meal; knowledge about which can be useful in determining the victim's whereabouts or actions prior to death (Bock and Norris, 1997). Some of these cell types include (Dickison, 2000):

- sclereids (pears)
- starch grains (potatoes and other tubers)
- raphide crystals (pineapple)
- druse crystals (citrus, beets, spinach)
- silica bodies (cereal grasses and bamboos)

In a case where a young woman had been stabbed to death, witnesses reported that she had eaten her last meal at a particular fast food restaurant. However, her stomach contents did not match the limited menu of the restaurant, leading investigators to conclude that she had eaten at some point after being seen in the restaurant. The investigation led to the apprehension of a man whom the victim knew, and with whom she had shared her actual final meal (Dickison, 2000). Time since death can be approximated by the state of digestion of the stomach contents. It normally takes at least a couple of hours for food to pass from the stomach to the small intestine; a meal still largely in the stomach implies death shortly after eating, while an empty or nearly-empty stomach suggests a longer time period between eating and death (Batten, 1995). However, there are numerous mitigating factors to take into account: the extent to which the food had been chewed, the amount of fat and protein present, physical activity undertaken by the victim prior to death, mood of the victim, physiological variation from person to person. All these factors affect the rate at which food passes through the digestive tract. Pathologists are generally hesitant to base a precise time of death on the evidence of stomach contents alone.

Other organisms

Bacteria, maggots and other organisms that may have ingested some of the subject matter may have also ingested any toxic substance within it.

Detection and Classification

Detection of drugs and pharmaceuticals in biological samples is usually done by an initial screening and then a confirmation of the compound(s), which may include a quantitation of the compound(s). The screening and confirmation are usually, but not necessarily, done with different analytical methods. Every analytical method used in forensic toxicology should be carefully tested by performing a validation of the method to ensure correct and indisputable results at all times. A testing laboratory involved in forensic toxicology should adhere to a quality programme to ensure the best possible results and safety of any individual.

The choice of method for testing is highly dependent on what kind of substance one expects to find and the material on which the testing is performed. Biological samples are more complex to analyze because of factors such as the
matrix effect and the metabolism and conjugation of the target compounds.

**Gas chromatography**
Gas-liquid chromatography is of particular use in examining volatile organic compounds.

**Detection of Metals**
The compounds suspected of containing a metal are traditionally analyzed by the destruction of the organic matrix by chemical or thermal oxidation. This leaves the metal to be identified and quantified in the inorganic residue, and it can be detected using such methods as the Reinsch test, emission spectroscopy or X-ray diffraction. Unfortunately, while this identifies the metals present it removes the original compound, and so hinders efforts to determine what may have been ingested. The toxic effects of various metallic compounds can vary considerably.

**Nonvolatile organic substances**
Drugs, both prescribed and illicit, pesticides, natural products, pollutants and industrial compounds are some of the most common nonvolatile compounds encountered. Screening methods include thin-layer chromatography, gas-liquid chromatography and immunoassay. For complete legal identification, a second confirmatory test is usually also required. The trend today is to use liquid chromatography tandem mass spectrometry, preceeded with sample workup as liquid-liquid extraction or solid phase extraction. Older methods include: spot test (see Pill testing), typically the Marquis Reagent, Mecke Reagent, and Froehde's Reagent for opiates, Marquis Reagent and Simon's reagent for amphetamine, methamphetamine and other analogs, like MDMA, the Scott's test for cocaine, and the modified Duquenois reagent for marijuana and other cannabinoids. For compounds that don't have a common spot test, like benzodiazepines, another test may be used, typically mass spectrometry, or spectrophotometry.

**References**

**External links**
Image Sources, Licenses and Contributors


File: Fingerprint Arch.png Source: http://en.wikipedia.org/w/index.php?title=File:Fingerprint_Arch.png License: unknown Contributors: Original uploader was Secfan at en.wikipedia. Later version(s) were uploaded by Sumruyinchester, Candroid02486, GuildNavigator48, Toomes57, Lupo at en.wikipedia.


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