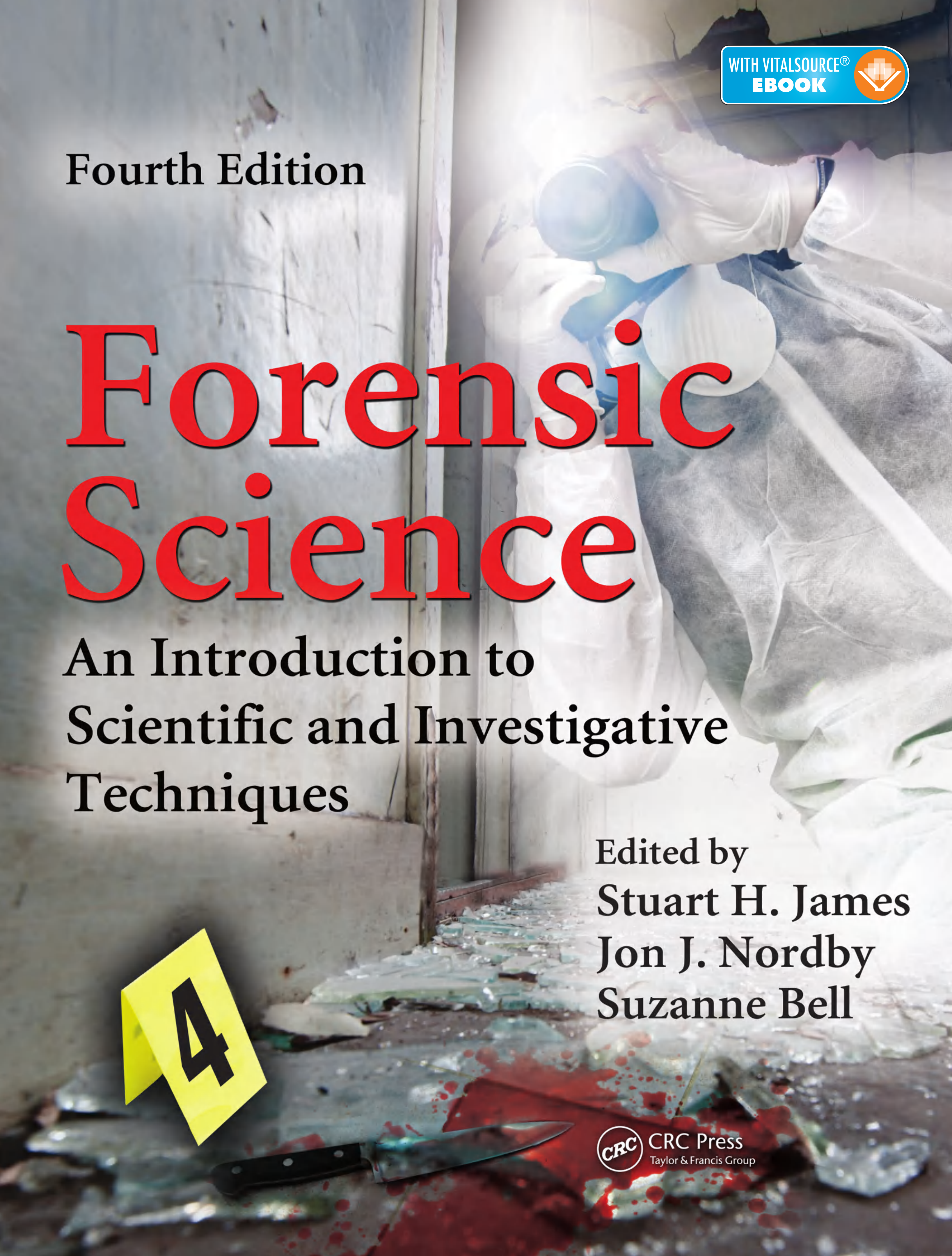


Fourth Edition

# Forensic Science

## An Introduction to Scientific and Investigative Techniques

Edited by
Stuart H. James
Jon J. Nordby
Suzanne Bell

CRC Press
Taylor & Francis Group

FORENSICS & CRIMINAL JUSTICE

# Forensic Science Fourth Edition

## An Introduction to Scientific and Investigative Techniques

Covering a range of fundamental topics essential to modern forensic investigation, the fourth edition of the landmark text Forensic Science: An Introduction to Scientific and Investigative Techniques presents contributions from experts in the field who discuss case studies from their own personal files.

**Designed for a single-term course at the lower undergraduate level, the book begins by discussing the intersection of law and forensic science, how things become evidence, and how courts decide if an item or testimony should be admissible. It takes the evidence from crime scene investigation into laboratory analysis and even onto the autopsy table for the fullest breadth of subject matter of any forensic text available. Topics include**

- Forensic anthropology and the role of entomology in a death investigation
- Death investigation, including identifying the cause, manner, mechanism, and time of death
- Bloodstain pattern analysis, the identification of blood and body fluids, the work of forensic toxicologists, and seized drug analysis
- The history and development of DNA typing and the many ways it can be used
- Fingerprint, firearm and ballistic, tool mark, tread impression, and trace evidence
- The forensic analysis of questioned documents and computers
- Arson, fire, explosives, and the work of forensic engineers in vehicular accidents and structural collapses
- Forensic psychology and psychiatry, including criminal profiling
- The future of forensic science

Going beyond theory to application, this text incorporates the wisdom of forensic practitioners who discuss the real cases they have investigated. Color-coded sidebars in each chapter provide historical notes, case studies, and current events as well as advice for career advancement. Each section and each chapter begins with an overview and ends with a summary, and key terms, review questions, and up-to-date references are provided. Appropriate for any sensibility, more than 300 photos from real cases give students a true-to-life learning experience.

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# Foreword to the Fourth Edition

More than ten years ago, to meet the need of instructors who called for a true introduction to the field of forensic science, the editors first conceived a textbook that would be comprehensive enough to cover the full breadth of the forensic sciences, yet engaging and basic enough to appeal to introductory classes. This would include disciplines as far ranging as biology and chemistry, crime scene and laboratory analysis, engineering and psychology, and even computer forensics and legal issues.

A lofty goal, indeed. Unfortunately, no *single* person could write such a textbook, so a group of experts was assembled to undertake the first contributed forensic science text, what became *Forensic Science: An Introduction to Scientific and Investigative Techniques*, edited by Stuart James and Jon Nordby. This textbook, published in September 2002, was developed with the help of contributors who had established themselves as the top experts in their field—individuals such as Marcella Sorg and William Haglund, anthropologists famed for their international work in the investigation of mass graves, and William Bodziak, author of the now classic *Footwear Impression Evidence*. Of course, the editors themselves are well known for both their books and their casework: James provides expert witnessing in bloodstain pattern analysis for high-profile cases, and Nordby is known for his innovative approach to crime scene reconstruction. Some of the contributors are also academics, but all have worked in the field, and all have provided the insights of their real-life experiences to the students who study this text. The full list of contributors with their affiliations may be found on the following pages, and they are all at the top of their respective fields.

Over several editions the book grew to include subjects such as photography and nursing. Although some instructors were pleased with the ever-increasing content and complexity, many asked for a more concise version, one that could be used for a single-term course at the lower undergraduate level. We responded. Working over two years with Matteson Editorial Developers, a team of instructors who vetted the content at each phase, and the pedagogical expertise of Suzanne Bell, a chemistry professor at West Virginia University, one of the U.S. universities accredited by the American Academy of Forensic Science, and the author of the acclaimed *Forensic Chemistry*, CRC Press is proud to continue the tradition established by the original textbook.

While providing a more concise and student-friendly version, *Forensic Science: An Introduction to Scientific and Investigative Techniques, 4th Edition*, blends the solid experience of practitioners, using real cases they investigated, with an increased pedagogy that includes chapter and section summaries, sidebars showing the educational pathway required to work in a particular branch of the science, provocative snapshots of cases taken from recent headline news, and up-to-the-minute references for further reading.

We hope you find the book useful and look forward to your feedback for the future.

**Becky Masterman**
*Senior Acquisitions Editor for Forensic Science*
*Taylor & Francis/CRC Press*

# Editors

**Stuart H. James** of James & Associates Forensic Consultants, Inc., is a graduate of Hobart College, where he earned a bachelor of arts degree in biology and chemistry in 1962. He received his MT(ASCP) in medical technology from St. Mary's Hospital in Tucson, Arizona, in 1963. Graduate courses completed at Elmira College include homicide investigation, bloodstain pattern analysis, and forensic microscopy. He has completed more than 400 hours of continuing education and training in death investigation and bloodstain pattern analysis. A former crime laboratory supervisor in Binghamton, New York, he has been a private consultant since 1981.

Mr. James has instructed in forensic science at the State University of New York and Broome Community College in Binghamton, New York. Additionally, he has lectured on the subjects of bloodstain pattern analysis and forensic science throughout the country and abroad, including the Tampa Police Academy; Southern Police Institute at the University of Louisville in Kentucky; Oakland County Sheriff's Department in Pontiac, Michigan; Nova Southeastern University Law School in Fort Lauderdale, Florida; University of Miami Law School in Coral Gables, Florida; University of Washington in Seattle; Suffolk University in Boston, Massachusetts; Henry C. Lee Institute at the University of New Haven in West Haven, Connecticut; Centre of Forensic Sciences in Toronto, Canada; Politie LSOP Institute for Criminal Investigation and Crime Science in Zutphen, the Netherlands; University of Newcastle upon Tyne; London Metropolitan Police in the United Kingdom; and Western Australian Police in Perth, Australia.

He has been consulted on homicide cases in 47 states and the District of Columbia, as well as in Australia, Canada, Germany, the Netherlands, Puerto Rico, South Korea, and the U.S. Virgin Islands, and has provided expert testimony in many of these jurisdictions in state, federal, and military courts.

Mr. James is a co-author of the text entitled *Interpretation of Bloodstain Evidence at Crime Scenes* and has contributed to other forensic texts, including *Introduction to Forensic Science*, *Practical Fire and Arson Investigation*, and *Practical Methodology of Forensic Photography*. He is also a co-author of the revised second edition of *Interpretation of Bloodstain Evidence at Crime Scenes* and the editor of *Scientific and Legal Applications of Bloodstain Pattern Interpretation*, both of which were published in 1998. He is a co-editor with Jon J. Nordby of the text entitled *Forensic Science: An Introduction to Scientific and Investigative Techniques*, first published in 2002 with the third edition published in 2009. He is also a co-author with Paul Kish and T. Paulette Sutton of the text entitled *Principles of Bloodstain Pattern Analysis: Theory and Practice* published in 2005. Mr. James is a fellow in the American Academy of Forensic Sciences and a distinguished member of the International Association of Bloodstain Pattern Analysts (IABPA) and is historian as well as current editor of the quarterly *Journal of Bloodstain Pattern Analysis*.

**Jon J. Nordby, PhD, D-ABMDI**, earned his advanced degrees from the University of Massachusetts–Amherst. He works as a forensic science consultant for Final Analysis, an independent consulting practice in death investigation, forensic science, and forensic medicine. He specializes in scene reconstruction and evidence recognition, collection, and analysis, as well as bloodstain pattern analysis and the investigation of police shootings. He serves the National Disaster Medical System as a medical investigator and forensic specialist with the Region X DMORT team. As such, he served in New York City after the World Trade Center terrorist attack. He is a professor emeritus and former department chair with Pacific Lutheran University and is a consultant with the BC Coroners Service Forensic Unit, King County Medical Examiners Office, Pierce County Medical Examiners Office, and Puyallup Police Department's Homicide Investigation Section. An instructor at the Washington State Criminal Justice Training Commission (Police Academy), Dr. Nordby formerly worked as a medical investigator and training officer with both the Pierce and King County Medical Examiner's Offices. A fellow of the American Academy of Forensic Sciences, he currently serves as General Section member of the Academy Board of Directors and member of the Academy's Ethics Committee. He belongs to the Association for Crime Scene Reconstruction, International Association of Bloodstain Pattern Analysts, Pacific Northwest Forensic Science Study Group, and Philosophy of Science Association. He formerly served as chair of the International Law Enforcement Expert Systems Association. His many publications include the book *Dead Reckoning: The Art of Forensic Detection* (CRC Press, 1999).

**Suzanne Bell, PhD**, earned a bachelor of science degree in 1981 from Northern Arizona University with a dual major in chemistry and police science (criminal justice). She ventured east for the first time that year and obtained her master's degree in forensic science from the University of New Haven in Connecticut. During the last year of that program, she did an internship with the New Mexico State Police Laboratory in Santa Fe and was offered a job. She began work there in 1983 while completing her master's thesis. She worked for the State Police as a forensic chemist during which time she processed dozens of crime scenes and testified over 80 times in local, state, and federal courts. In 1985, she moved north to Los Alamos National Laboratory (LANL), where she worked as an organic analytical chemist in the environmental chemistry group. For about two of those years she served as section leader of the organic analysis group.

In 1989, she took the leap and returned to graduate school, seeking a doctorate in chemistry from the research group of Dr. Gary Eiceman at New Mexico State University (NMSU). She moved to Las Cruces and completed the degree in 1991. Her research focused on ion mobility spectrometry, and the application of statistical methods and chemometrics to information management system (IMS) data. She returned to LANL and stayed there until 1992. Bitten by the academic bug, she completed a postdoctoral appointment at NMSU before joining the chemistry department at Eastern Washington University in 1994. She worked with the Washington State Patrol (WSP) to establish a bachelor of science option in the chemistry department in forensic chemistry, and the WSP built a new forensic laboratory on the campus in 2003. She also developed an interdisciplinary program in environmental science.

In 2003, she moved to a research position and joined the faculty of West Virginia University in the chemistry department, analytical division, where she assists both the department and the forensic and investigative sciences (FIS) in the forensic chemistry track. She oversees several master's students from FIS as well as her group of chemistry doctoral students. She was tenured in 2011 and is now an associate professor with research interests in gunshot residue, forensic toxicology, ion mobility spectrometry, and chemical data analysis.

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# SECTION I

# Setting the Stage

## Section Overview

> [Crimiinalistics (forensic science)] is concerned with the unlikely and the unusual. Other sciences are concerned primarily with the likely and the usual. The derivation of equations, formulas, and generalizations summarizing the normal behavior of any system in the universe is a major goal of the established sciences. It is not normal to be murdered, and most persons never experience this unlikely event. Yet, when a murder occurs, some combination of circumstances suddenly alters the situation from unlikely to certain.

The above is a quotation from one of the pioneers of American forensic science, Paul Kirk (1902–1970). It captures the uniqueness of forensic science within the broader context of the natural sciences and engineering. The forensic scientist serves two masters—science and the legal system. This is not the natural pairing that you might expect it to be. In this section, we study the evolution of forensic science to what it is today, look at how the forensic scientist interacts with the legal system, discuss the concept of evidence, and learn how forensic scientists work within the two worlds.

# 1
# Justice and Science

## Chapter Overview

> … When a man who is honestly mistaken hears the truth, he will either cease being mistaken, or cease being honest.
>
> **Thomas Paine (1737–1809)**

The hard chair in the witness stand is much like the hard seat in the classroom—good for keeping one alert, bad for inducing comfort. But neither the courtroom nor the classroom is designed for comfort. Ideally, along with any discomfort, the occupants of both the witness chair and the classroom desk also share the quest for truth, or as near to truth as humanly possible. It is often thought that science and justice, like science and learning, have the same goal—elucidation of the truth. However, this is an oversimplification that masks the complexity of the intersection of justice and science where this book was born.

It may surprise you to learn that the ultimate goal of litigation is not to find truth. Any system that allows a jury to reach a verdict of "guilty" or "not guilty" in such important matters would appear to have something else in mind. The hope of the American litigation system is to provide the best, fairest, and optimal context for a jury to find the truth and use that truth to settle a dispute. Creating such an environment is a complex challenge that involves scientists and lawyers, professionals that approach their work from surprisingly different perspectives. In this chapter, we will explore these different perspectives, beginning with a very brief overview of the history of law and forensic science. We will also explore the similarities and surprising differences between science and the law and discuss ethics as it relates to forensic scientists.

# Chapter 1
# Justice and Science*

*Jon J. Nordby and Suzanne Bell*

## Chapter Outline



## 1.1 A Brief History of Forensic Science

### *1.1.1 Overview*

We could never hope to cover all aspects of the history of forensic science here, but we can address the highlights that will help you understand how forensic science began, how it evolved, and how it developed into the diverse field that it has become today. Most chapters will also cover history of that particular subject to round out your knowledge. The reference section at the end of the chapters lists several books that discuss the history of forensic science in detail. Forensic science arose out of other sciences such as biology, chemistry, medicine, and pharmacology (how drugs and poisons interact with the body). An important early driving force was death investigation, which we will examine in Section III, Chapters 5, 6, and 7. This history of death investigation is surprisingly long. Consider the following commonsense advice quoted from a forensic text:

* This chapter is based in part on Chapter 1, "Here We Stand: What a Forensic Scientist Does," and Chapter 34, "Countering Chaos: Logic, Ethics, and the Criminal Justice System," both by Jon J. Nordby, as published in the third edition of this text.

> The similarities between those who jump into wells, those who are thrown in, and those who lose their footing and fall are very great. The differences are slight. … If the victim was thrown in or fell in accidentally, the hands will be open and the eyes slightly open, and about the person he may have money or other valuables. But, if he was committing suicide, then his eyes will be shut and the hands clenched. There will be no valuables on the body. Generally, when someone deliberately jumps into a well, they enter feet first. If a body is found to have gone in head first, it is probable that the victim was being chased or was thrown in by others. If he lost his footing and fell in, you must check the point where his feet slipped to see if the ground has been disturbed.

There is nothing remarkable about this passage, except that it was written in 1247 CE and was printed in a book in China entitled (translated) *The Washing Away of Wrongs*. Although the investigation of death was only one motivating force in the development of forensic science, it certainly was one of the most important.

### 1.1.2 Key People in the History of Forensic Science

One way to discuss the history of forensic science is to look at the key historical figures. Below are brief descriptions of some of these people, listed in alphabetical order. We will meet up with them again in later chapters. You will notice that most of these scientists worked from the mid-19th century on; this was the era in which forensic science began to coalesce as a recognizable discipline, first in medicine and then in a more general sense. You will also notice that most of these scientists are European, as at the time Europe was the source of many scientific advances in general. Finally, notice that most of these scientists were **generalists** in that they worked in many forensic disciplines. Today, forensic science has moved to more of a **specialist** model in which a forensic scientist specializes in one forensic discipline such as trace evidence analysis or questioned documents.

#### *Balthazard, Victor (1852–1950), French*

***Figure 1.1*** Victor Balthazard.

Victor Balthazard (Figure 1.1) served as the medical examiner for the city of Paris and helped advance fingerprint, firearms, and hair analysis at a time when forensic science was emerging as a distinct scientific discipline. He is credited with developing probability models that showed that fingerprints were unique and that there is approximately one chance in $10^{60}$ (1 followed by 60 zeros) that any two people will have the same patterns. To grasp the significance of that number, a one in a trillion chance is expressed as one chance in $10^{12}$. In 1910, he, along with Marcelle Lambert, wrote the first comprehensive book on hair analysis entitled (translated) *The Hair of Man and Animals*. Balthazard also developed an advanced photographic method of comparing markings on bullets and in 1912 testified in a case using photographs and point comparison techniques to identify bullets involved in a fatal shooting. He was also among the first to note other distinctive markings in firearms, including firing pin impressions and fabric impressions that result when a soft lead bullet passes through woven fabrics.

### *Bertillon, Alphonse (1853–1914), French*

***Figure 1.2*** Alphonse Bertillon.

Alphonse Bertillon (Figure 1.2) developed the first systematic method for the identification of suspects and criminals, but it was not based on fingerprints; rather, his system, called **anthropometry** or **Bertillonage**, used 11 body measurements along with descriptive information and photographs stored on a card. After development and implementation in France in 1883, the system spread throughout the world and elevated Bertillon to the forefront of pioneering forensic scientists. The system remained widely used into the early 1900s, when fingerprints began to replace it.

Bertillon resisted the use of fingerprints, although he did add space to his data cards for the inclusion of fingerprint data from the right hand of the individual being cataloged. Ironically, despite his reluctance to accept fingerprinting, Bertillon was the first forensic scientist in Europe to use them to solve a case. In October of 1902, he used fingerprints left at a crime scene to identify the murderer, a convicted swindler whose prints had been taken and cataloged on his Bertillon card. The man later turned himself in and confessed. A less successful outing came in a later case. When the Mona Lisa painting was stolen in 1911 from the Louvre Museum in Paris, Bertillon was unable to identify the suspect even though he left prints on the glass covering the painting. Unfortunately for Bertillon, these prints were from the left hand and his cards stored prints only from the right. Despite the growing evidence of the superiority of fingerprints for individual identification, it was not until after Bertillon's death that the transition was complete. (See Sidebar 1.1.)

### *Galton, Sir Francis (1822–1911), English*

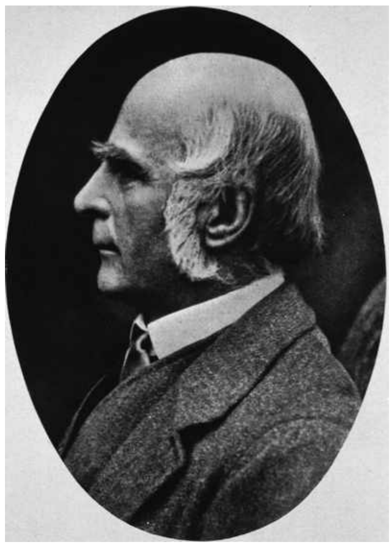

***Figure 1.3*** Sir Francis Galton.

Sir Francis Galton (Figure 1.3), a cousin of Charles Darwin, started collecting thumbprints in 1888. He is credited with developing the first classification system for fingerprints (Figure 1.4), which was adopted by the British government as an adjunct to the Bertillon system. In 1892, he published the influential book *Finger Prints*, which helped bring fingerprinting to the forefront of criminal identification. It is still considered to be one of the primary references in the field. Galton also was the first proponent of classification using the basic patterns of the loop, arch, and whorl. In the United States, the term "Galton ridge" is used to describe one of the features found in fingerprints.

**SIDEBAR 1.1. HISTORICAL NOTE: THE WILL WEST CASE**

Bertillonage was widely adapted across the world as a means of criminal identification. Body measurements collected were recorded on a card that also contained a photograph of the person. One of the cases that hastened the change from Bertillonage to fingerprints was that of Will West (or the two Will Wests). In 1903, a man named Will West was sent to Leavenworth Prison in Kansas. When he arrived, he was sent for collection of his measurements. The clerk on duty thought that he recognized the man and asked if he had been processed at Leavenworth before. He said that he had not. The clerk searched his records and found one for William West, a man who looked nearly identical to Will West. Not surprisingly, their Bertillon measurements were nearly identical as well. It is unknown if these men were related, but what was clear was the need to move away from Bertillonage as a means of criminal identification.

### *Goddard, Calvin (1891–1955), American*

Dr. Calvin Goddard is often credited with establishing scientific examination of firearms evidence in the United States, much as Balthazard helped to do in Europe. Around the turn of the 20th century, forensic firearm examination was neither systematic nor reliable, and many of the experts called to testify were self-proclaimed and questionable at best. Goddard, a retired Army physician and gun enthusiast, helped to change the situation. As a physician, he had risen to directorship of The Johns Hopkins Hospital in Baltimore, Maryland. In 1925, he joined the Bureau of Forensic Ballistics, a private organization, and worked on several famous cases. As a result of his growing reputation, Goddard was called to examine evidence of the infamous St. Valentine's Day Massacre in Chicago in 1929. He was able to show that all of the victims had been killed by two Thompson submachine guns. Some of the jurors in that case later raised money to establish a forensic laboratory at Northwestern University in Evanston, Illinois, called the Scientific Crime Detection Laboratory. Goddard was appointed as the first director of the laboratory and stayed until 1932. The laboratory moved to Chicago and became the Chicago Police Department laboratory in 1938. Goddard also assisted the FBI in establishing firearms analysis capability at their new lab, inaugurated in 1932. Some of the tools used in modern firearms examination were developed by Goddard and co-workers (see Figures 1.5 and 1.6).

***Figure 1.4*** A fingerprint.

***Figure 1.5*** Comparison scope. This is the type of instrument used by firearms examiners today using methods pioneered by Goddard.

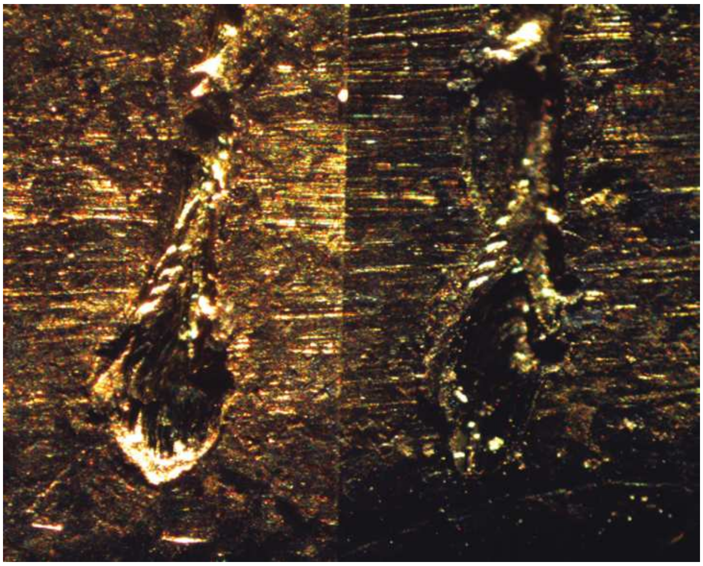

***Figure 1.6*** Bullets being compared using the comparison microscope.

### *Gross, Hans (1847–1915), Austrian*

Hans Gross, an examining magistrate in Graz, Austria, is the man credited with coining the term **criminalistics** to describe forensic analysis of physical evidence. Gross viewed forensic science holistically and believed that experts from diverse fields would contribute to the analysis of physical evidence and solving crimes. He was a generalist in the purest sense of that word. He understood the value of biological evidence, soil, dust, and many other types of transfer and trace evidence. In 1893, he published the first textbook in forensic science, which was translated into English under the title of *Criminal Investigation*, and he started a journal called *Kriminologie*, which is still published.

### *Holmes, Sherlock*

Although fictional, no history of forensic science would be complete without mentioning the role these stories played in shaping the public's image of forensic science. Over the course of 40 years (1887 to 1927), Sir Arthur Doyle published 56 short stories and 4 novellas starring Holmes and his good-humored assistant, Watson, as they solved crimes using logic and science. In his career, Holmes delved into many areas of forensic science, including forensic biology, trace and transfer evidence, firearms, and questioned documents, using fictional techniques that in many cases accurately predicted later developments in the field. Doyle's stories influenced and inspired many of the pioneers of forensic science including Hans Gross and Edmond Locard. Holmes is best described as a forensic chemist, although his scientific interests and skills were broad and deep. In *A Study in Scarlet*, Holmes announces the discovery of the "Sherlock Holmes" test, a chemical reagent that detected not just blood, but specifically human blood. This was in 1887, 14 years before an immunological test for human blood was announced in 1901. It was not until 1904, 17 years later, that a presumptive test for blood that reacts with hemoglobin was developed. As Doyle wrote:

> "I've found it. I've found it," he shouted to my companion, running towards us with a test tube in his hand. "I've found a reagent which is precipitated by hemoglobin and by nothing else. … The old guaiacum test is very clumsy and uncertain. So is the microscopic examination for blood corpuscles. The latter is valueless if the stains are a few hours old. … Are they blood stains, or rust stains or fruit stains, or what are they? This is a question which has puzzled many an expert and why? Because there was no reliable test. Now we have the Sherlock Holmes test, and there will no longer be any difficulty."

The guaiacum test was the oldest presumptive test for blood and, like all presumptive tests, was subject to false positives, meaning that the reagent would react with materials other than blood. The other option he mentions, looking for red blood cells (corpuscles), only works on fresh stains that are still wet. Once a stain dries out, the cells lyse (break open) and are no longer recognizable under a microscope. As occurs in many kinds of fiction, a hero from literature manages to accurately predict developments years ahead of their time. As a character, Sherlock Holmes has been constantly revised and reinvented in movies and on television. For a modern take on forensic science in fiction, see Sidebar 1.2.

#### SIDEBAR 1.2. CURRENT EVENTS: FORENSIC FICTION

The way a real forensic laboratory works is a far cry from what is usually depicted in the media, particularly in recent television shows. Although it is true that each laboratory operates differently, there are common elements; for example, crime scenes are usually handled by crime scene personnel specially trained to document a scene, process and collect evidence, and deliver it to the appropriate forensic personnel. It is becoming increasingly rare for laboratory-based scientists to venture to crime scenes. Conversely, crime scene investigators usually do not perform subsequent forensic analysis of the evidence collected. Often, crime scene personnel are trained in bloodstain pattern analysis, but they would not usually perform testing on a firearm collected at the scene. That task would fall to the forensic firearms analyst in the forensic laboratory. The lesson is that readers interested in a career in forensic science need to be aware of how modern forensic science is practiced in the real world rather than in the fictional.

***Figure 1.7*** Fibers under crossed polars. Fibers are a type of trace evidence.

### *Locard, Edmond (1877–1966), French*

Edmond Locard was trained in both law and medicine. In 1910, he established a forensic laboratory in Lyon, France. The lab was primitively equipped, but even so Locard was able to establish a reputation and to increase the visibility of forensic science in Europe. Locard was interested in microscopic and trace evidence (Figure 1.7), particularly dust, and believed that such trace evidence was crucial in linking people to places. Although he apparently never used the exact phrase himself, Locard is most famous for developing **Locard's exchange principle**, which evolved from his studies and writings. The principle is usually paraphrased as "every contact leaves a trace," reflecting his belief that every contact between a person and another person or a person and a place results in the transfer of materials between them. The success of his laboratory and methods encouraged other European nations to form forensic science laboratories after the conclusion of World War I. In Lyon, he founded and directed the Institute of Criminalistics located at the University of Lyon, and he remained a dominant presence in forensic science into the 1940s.

### *Orfila, Mathieu (1787–1853), Spanish, French Forensic Toxicologist*

Mathieu Orfila (Figure 1.8), considered the founder of forensic toxicology, was born in Spain but moved to France where he worked and became professor of forensic chemistry and dean of the medical faculty at the University of Paris. He began publishing early, with his first paper on poisons in 1814 when he was 26 years old. He spent a good deal of time studying poisons, particularly arsenic, which was frequently used for murder in that era. As a toxicologist, he concentrated on methods of analysis of poisons in blood and other body fluids and tissues. He became involved in a famous arsenic poisoning case in 1839, when a young woman, Marie Lafarge, was accused of using arsenic to

***Figure 1.8*** Mathieu Orfila

murder her much older husband. Initial results of the analysis of the husband's body were negative, but Orfila was able to detect arsenic in the exhumed remains. Marie was eventually convicted of the crime. His testimony in the case was one of the earliest examples of sound scientific testimony by a recognized scientific expert in a court of law.

## 1.2 Science and the Law Today

Lawyers and forensic scientists enjoy a close, yet often uneasy, relationship. In this sense, at least, forensic scientists and lawyers speak different languages with different objectives, although unfortunately using many of the same words. The words "truth," "fact," "certainty," "possible," and "probable" can mean very different things in law and in science. Lawyers work in adversarial situations where the clear objective remains winning a favorable decision for one's client through knowledge of the law. The adversarial system depends for its success upon the vigilance of opposing counsel, who also works toward the same objective. In this sense, law is outcome based. In law, a judge or a jury (**finder of fact** or **trier of fact**) determines the truth. What juries or judges say, through their verdicts, is what is so.

In contrast, science is data based and founded on concepts that taken collectively are called the **scientific method**. The goal of science, broadly speaking, is to improve our understanding of the natural world. This goal has nothing to do with justice directly. In science, understanding "truth" or as close as one can come to it, depends upon the available evidence combined with a reliable method. Scientists remain dependent upon data and present their conclusions as tentative, conditional, or probable in nature where appropriate.

The scientific method can be thought of as a series of steps:

1. Formulate a hypothesis (a tentative idea or explanation).
2. Test the hypothesis using observation or experimentation.
3. Based on the results, revise the hypothesis and repeat.
4. Continue until the data are in agreement with the hypothesis.

This list provides a useful way to organize a discussion of method for what we call the "natural sciences." However, the list is not meant to name the steps to take in the actual activities of working as a forensic scientist. The sciences begin with data—information, or facts—not with hypotheses. Scientists observe and collect facts. They then develop measurements—for example, the length, width, mass, or some other feature of interest. These facts are studied to develop useful relationships one to another—for example, in medicine, the weight of a patient and that patient's blood pressure. Only then do scientists begin formulating hypotheses; for example, after a medical examination, a researcher could form the hypothesis that "as a patient's weight increases, that patient's blood pressure increases." That researcher could then formulate tests for the hypothesis that evaluate varying weights (as measured) and blood pressures (as measured) to discover any relationships among them that might help explain, in this example, the fact of high blood pressure. This model, however, does not apply to the justice system.

Lawyers represent one of two rival positions arguing for acceptance, and this is called the **adversarial system**. The two models—the scientific method and the adversarial system—make for an odd couple. They may be operating with a different set of facts. The scientist may present the data, but the lawyer may argue that the data are inadmissible and prevent the data from becoming evidence. Where a scientist may see a complex issue consisting of many related parts whose interactions may be unclear to varying degrees, a lawyer may see the issue simply as yes or no, black or white, on or off, true or false. In other cases, what the scientist sees as black and white data may become more complex in the law's view.

How then can the two systems (justice and science) find a way to serve their mutual goals? Science is not flexible; it must be data centered and data driven. With that in mind, it is possible to detail some of the ways that scientific data and investigation can be presented to a court. Specifically, forensic science should, among other things:

1. Help distinguish evidence from coincidence without ambiguity.
2. Allow alternative results to be ranked by some principle basic to the sciences applied.
3. Allow for certainty and probabilistic considerations wherever appropriate through this ranking of relevant available alternatives.
4. Disallow hypotheses more extraordinary than the facts themselves.
5. Pursue general impressions to the level of specific details.
6. Pursue testing by breaking hypotheses (alternative explanations) into their smallest logical components, addressing one part at a time.

A reasonable model for thinking about the goals, objectives, and practices of forensic science is medicine, an area in which we all have some experience and understanding. A physician attempts to diagnose an illness based on data obtained from observation, testing, and questioning. In the forensic sciences, we reason from a set of given results (a crime scene, for example) to their probable explanations (hopefully, a link to the perpetrator). The aims of forensic science and medicine rest with developing justified explanations. Obviously, not all forensic explanations are alike. Some involve entirely appropriate statistical assessments and degrees of error suitably dependent on accurate mathematical models and accurate population studies. You will see such explanations, for example, when studying DNA and other population-based sciences presented in this text. However, not all forensic scientific explanations involve such statistical issues. Instead, individual, non-repeatable events with no statistical characteristics may demand scientific explanation.

A medical diagnosis involves selecting the best explanation of abnormalities in the observed data from among the clinically available alternatives. The diagnosis concerns what is wrong with one individual, not just what affliction correlates to some population group. In forensic medicine, the diagnosis focuses on the cause and manner of an individual's death. Although statistics are applied differently than in DNA, pathologists do see similar cases over time and use their experience in making their determinations; for example, a forensic pathologist may testify that he has "seen this in 10 cases" to add a quantitative dimension to his presentation.

In either clinical medicine or in the forensic sciences, how one's opinion is constructed determines its certainty. The certainty of forensic explanations is measured by assessing their explanatory justifications. This, in turn, involves showing, first, that the explanation is justified, and, second, that the explanation is better justified than any available alternative explanation. In this forensic setting, certainty assessments address the scientific explanation's rational justification, leaving the question of the explanation's truth and role in legal deliberations to the court. This allows for a clearer understanding of requests for certainty assessments when scientists are asked by attorneys to attach some degree of certainty to their work product.

All reliably constructed scientific explanations are best viewed as works in progress. We could always learn additional facts that may alter our views. Sometimes, however, no additional information would be relevant. In either case, our opinions must be held with what American philosopher and scientist Charles Sanders Peirce called *contrite* ***fallibilism***—an awareness of how much we do not know and the humility to acknowledge the possibility of making mistakes. Forensic scientists must develop an intellect not too sure of what must remain uncertain and not too uncertain about what must remain sure.

## 1.3 Modern Practice of Forensic Science

Many, but not all, forensic scientists work in public and private forensic laboratories. The remainder work outside of the laboratory systems as independent consultants and contractors. Some practitioners that work in laboratories also take on private casework, combining the two settings. People who work in fields such as forensic anthropology or forensic engineering are typically private consultants; often these types of professionals work at universities. Often, forensic work is only part of their job. On the other hand, forensic scientists working in public and private forensic laboratories generally work full time in the profession. **Public laboratories** are those funded by governments such as states, counties, and cities. **Private laboratories** are businesses that are designed to make a profit; most of these labs specialize in DNA and forensic toxicology.

There is no such thing as a typical forensic science laboratory. The laboratory system in one state can be completely different than that in the neighboring states. Some cities and counties maintain forensic laboratories, while rural states often rely on only one state laboratory. One laboratory might be full service, while another might perform a subset of forensic analyses. The federal government is home to several agencies that maintain forensic laboratory systems; examples include the Drug Enforcement Administration (DEA, www.dea.gov); Secret Service (http://www.secretservice.gov/forensics.html); Federal Bureau of Investigation (FBI, http://www.fbi.gov/about-us/lab), and Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF, www.aft.gov). These laboratories focus on the forensic disciplines that are most critical to that particular agency. The military also maintains a complete forensic science system, including a full-service forensic laboratory near Atlanta, Georgia (Armed Forces DNA Identification Laboratory, http://www.cid.army.mil/usacil.html) and the Armed Forces Medical Examiner System (http://www.afmes.mil/), which focuses on death investigation and toxicology.

In many states, the Office of the Chief Medical Examiner is tasked with death investigation (see Section III) and houses the laboratories associated with performing autopsies. Often, these facilities will have toxicology laboratories onsite so that postmortem samples such as blood and tissue can be analyzed there as well. A full-service forensic laboratory usually covers disciplines such as DNA, drug analysis, firearms and toolmarks, trace evidence, fingerprints, questioned documents, or some combination of these disciplines. One well-known example of a full-service laboratory is the FBI laboratory in Quantico, Virginia. Conversely, there can be small branch laboratories that work exclusively on one type of evidence, such as seized drugs. Increasingly, crime scene response is being handled by police departments and units such as major crime scene squads. In these scenarios, forensic scientists are also police officers and their primary job is to respond to crime scenes, process and collect evidence, and deliver that evidence to the appropriate agency for further testing. These officers may work with some types of evidence such as fingerprints, but they usually do not get involved in the other forensic specialties.

One of the most important developments of the past few years related to forensic science laboratories is the increasing attention being paid to **accreditation**. Many kinds of laboratories are accredited; for example, clinical laboratories in hospitals that perform blood tests are accredited. Accreditation means that a laboratory has agreed to operate according to a professional or industry standard and has proven that it can and does operate this way. The process of obtaining accreditation is often long and complex and involves planning, documentation, recordkeeping, training, and site visits by the accrediting agency. Once a laboratory is accredited, it must be reaccredited on a set schedule, such as every 5 years.

Accreditation is increasingly being demanded of forensic laboratories. As noted by in the 2009 National Academy of Sciences (NAS) report entitled *Strengthening Forensic Science in the United States: A Path Forward*, "Laboratory accreditation and individual certification of forensic science professionals should be mandatory. … All laboratories and facilities (public or private) should be accredited." Currently, the largest forensic accrediting body is the American Association of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB, http://www.ascld-lab.org/). As of 2012, 390 laboratories in the United States and abroad were accredited by ASCLD/LAB. Currently, accreditation is voluntary.

The other issue noted in the NAS quote is that of analyst **certification**. Certification means that a forensic scientist has completed a written test covering his or her discipline and that the analyst participates in yearly proficiency testing to ensure that their laboratory methods and techniques are sound. Because forensic science is such a broad discipline, accreditation is not currently the responsibility of a single organization. For example, forensic toxicologists are certified by the American Board of Forensic Toxicology (http://www.abft.org/), an organization that also accredits certain types of forensic toxicology laboratories. The National Association of Medical Examiners (NAME, www.thename.org) accredits medical examiner's offices, and the American Board of Pathology (ABP, www.abpath.org) certifies doctors in forensic pathology. The International Association of Identification certifies several forensic disciplines (www.theiai.org). The American Board of Criminalistics (ABC, www.criminalistics.com) covers the most diverse set of forensic disciplines from chemistry to toolmarks. The certification process begins by passing a multiple-choice test. Forensic scientists can then elect to be further certified in a specialty area. Currently, these areas are molecular biology, drug analysis, fire debris analysis, trace evidence (hairs and fibers), and trace evidence (paint and polymers). This level of certification requires the successful annual completion of proficiency tests.

## 1.4 Types of Legal Proceedings

### *1.4.1 Overview*

A key part of most forensic science jobs is interacting with the justice system through various procedures and mechanisms. Sometimes, all that is required is a signed report, and the forensic scientist's role in the case ends. At other times, days spent in grueling testimony are required before a judge, jury, and even national television audiences. We will discuss the most common ways, but certainly not the only ways, in which a forensic scientist interacts with the judicial system. Broadly speaking, the legal system in the United States can be divided into the realm of **civil law** and **criminal law**. To simplify, civil cases are cases between individuals or parties, the common meaning of the terms "lawsuit" or "being sued." For example, a victim's family may sue a suspected or convicted murderer in a civil case on a "wrongful death." Another example is a patent infringement suit in which one company has accused another of violating a patent. On the other hand, criminal cases involve violation of criminal laws and involve the government as the body that is charging an individual, individuals, or companies with violation of criminal laws. Typically, the party that files criminal charges is called the **prosecution** (**plaintiff** in civil actions) and the accused is the **defendant**. Forensic scientists can testify in either type of legal action and for either party, the accused or the defendant.

Various levels of government can be involved in legal proceedings—local (cities and counties, for example), state, or federal. A **jurisdiction** is a region or geographical area over which law enforcement or a legal entity can excise authority. In the United States, different legal rules and procedures often apply depending on the jurisdiction in which the procedure is conducted. For example, the rules that apply in the city of New York may differ from those Chicago, which may differ from the rules that apply in the states of New York and Illinois, which in turn may differ from rules used in federal courts. As an example, a person who sells a sample of an illegal drug in a state may be tried at a local or state level. If that same person smuggles drugs across state lines, then federal jurisdiction applies. The legal procedures may be similar, but they are not necessarily the same. We will discuss this in the context of admissibility in detail in the next chapter.

It is important to know to whom evidence is presented and who will make the decision based on the evidence presented. This entity is defined as the trier of fact, which can be a jury of some type or a judge. A **grand jury** is a special type of jury that is empowered to decide if the evidence against a defendant warrants proceeding to the next step. If the jury decides there is sufficient evidence to warrant further action, this is referred to as *handing down an indictment*. In other cases, some form of preliminary hearings may be required. In a criminal proceeding, the prosecutor bears the burden of proving a defendant guilty beyond a reasonable doubt, a burden that never shifts. However, in a civil case, the plaintiff need only prove his case by a preponderance of the evidence, a much easier standard to meet. Informally, *beyond a reasonable doubt* might be thought of as 99% certainty, while *preponderance of evidence* would be 51%. These are not hard numbers but examples to put the difference between civil and criminal burdens in perspective. Criminal cases are divided into the more serious (**felony**) vs. less serious (**misdemeanor**), a division that is important in determining the severity of the punishment handed out to a defendant found guilty.

### 1.4.2 A Forensic Scientist's Day in Court

You may be surprised to learn that most of the cases forensic scientists process do not end up in court as you probably imagine it, in a packed courtroom before a judge and jury. Reasons for this include failure to apprehend a suspect, charges not being filed, the suspect reaching a plea agreement (plea bargaining), or a stipulation agreement, where the expert's report is accepted as fact and their testimony is not required. When the forensic scientist does testify, the process can be generalized to some extent.

Once the laboratory analysis is completed, a report is written and sent to the officer or agent that submitted the evidence. The report is then shared with prosecuting attorneys and, if charges are filed, with the defense. If a trial is scheduled and the forensic scientist is required to testify, a **subpoena** is delivered to the scientist that states when and where the trial is to be held. The analyst is required to appear under penalty of law.

After the scientist takes the witness stand and is sworn in, the first task is to establish that he or she is qualified to offer expert testimony to the court. This is accomplished by the ***voir dire***, where the prosecution introduces the scientist and then has that person describe his or her qualifications, including academic background, training, and experience. The defense can ask questions of experts and may attempt to discredit them. Normally, at the end of this procedure, the forensic scientist is accepted as expert by the trier of fact and allowed to testify about the case being tried.

Next, the prosecution begins the **direct examination**, which can take a descriptive or question-and-answer format. One of the goals of the direct examination is to lay the foundation for the admissibility of the evidence in question. The defense has the opportunity to attack the admissibility of the evidence much as they have the opportunity to attack the qualifications of the expert during the *voir dire* procedure. If the evidence is not ruled admissible, the expert is not allowed to testify about work done on it or conclusions reached.

At the conclusion of the direct examination, the defense has the opportunity for **cross-examination** of the witness if they so desire. After the cross-examination, the prosecution can again ask questions in the redirect, followed by recross. This cycle continues until both parties are satisfied and there are no further questions. The duration of expert testimony varies based on the complexity of the case and the laboratory analysis involved. Many simple drug analysis cases may involve only a few minutes, while more complex cases may require days on the stand. Once the final recross is complete, the witness is excused and is either allowed to leave (dismissed) or told to remain available for possible recall.

## 1.5 Ethics and Forensic Science

The importance of ethics as part of forensic science is obvious. As with most professions, there are formal written codes of ethics that members of professional societies agree to and are expected to follow. However, because there are so many different subdisciplines in forensic science, there is no one code of ethics that covers all forensic scientists. The American Academy of Forensic Sciences (AAFS, www.aafs.org) has a code of ethics and an ethics committee that deals with ethics issues and challenges. Other societies and groups have separate codes. Examples include the Society of Forensic Toxicology (www.soft-tox.org), the American Society of Questioned Document Examiners (www.asqde.org), and the organizations discussed in the section describing accreditation. However, as we all know, having a code of ethics does not always prevent ethical lapses from occurring. In a profession such as forensic science, these ethical lapses can have serious and long-term effects. (See Case Study 1.1.)

The fundamentals of forensic ethics are simple to define in a broad sense. First is ethics, which we can think of as a set of rules the govern conduct of a professional working in a given field. These rules define what is considered to be proper,

**CASE STUDY 1.1: THE NOVELIST, MURDER, AND ETHICS**

One of the most interesting forensic cases in recent memory has been playing out in North Carolina since 2001. In December of that year, Michael Peterson, who penned several best-selling novels, called police to report that his wife had fallen down a flight of stairs and was not breathing. She died shortly after police arrived at the scene, which had a significant amount of spilled blood. Peterson maintained that she had been drinking and likely fell accidentally while he was sitting out by their pool. The medical examiner found injuries that were inconsistent with a fall and Peterson was arrested, indicted, and eventually convicted of murder in 2003. One of the key prosecution witnesses was a bloodstain pattern analyst from the North Carolina State Bureau of Investigation (SBI). The SBI had been the subject of state inquiries and investigations from 2009 to 2010, and as a result of these investigations and the appeals process the analyst was subsequently fired in 2011. Among the allegations against him was that he overstated his qualifications and experience in the area of bloodstain pattern analysis. Peterson was granted a new trial and released in December of 2011, and the case continues to unfold.

acceptable, and honest behavior within that discipline. Here, a forensic scientist is expected to do the best work that they can on every case that is submitted, provide a complete and honest report of their work, and testify as to their scientific opinion based on that report and their knowledge in the field. This does not imply that disagreements between two experts automatically mean that one of the scientists is being unethical—far from it. In complex cases that involve opinion evidence such as crime scene reconstruction, death investigations, and toxicological testing and data interpretation, different experts often have different opinions that are derived from the same data. It is important to remember that testimony provided by accepted scientific experts is still opinion evidence. The degree to which expert opinions can be reasonably expected to disagree usually depends on the complexity of a case. You would not expect two experienced forensic chemists to disagree over the identification of a white powder as cocaine, for example, but you can reasonably expect two bloodstain pattern experts to disagree over stains found in a large and complex crime scene. It is up to the experts to present their opinion and defend it, but in the end it is the trier of fact that will decide how that testimony is integrated into their decision in the case.

Another ethical issue that arises in forensic science is that of bias. For example, if a forensic DNA analyst works for a laboratory that is run by a law enforcement agency, what are the obligations of that analyst in any case? Are they expected to find results that support their submitting agency? This is sometimes referred to as **prosecutorial bias**. Forensic scientists have to be constantly aware of their primary responsibility, which is to perform scientific analyses and report their results regardless of how the results might help or hurt the agency's case. It is not the forensic scientist's job to identify the guilty party and make sure they are punished; rather, their job is to supply scientific data and information that can be used to find the truth in any given case, regardless of who or what their data support, incriminate, or exonerate.

## Chapter Summary

Forensic science as it is recognized today traces its beginning back thousands of years and was driven by the need to investigate suspicious deaths. Development accelerated in the 19th century, mostly in Europe, where many of the early forensic scientists practiced in many areas that are today considered to be separate forensic disciplines. The concept of a modern forensic laboratory took shape in the 20th century, and today forensic scientists work in public and private labs and as private consultants. All interact with the legal system in different ways, much depending on the type of casework they do and report on. Accreditation of laboratories and certification of analysts are becoming increasingly important, as are ethics and consolidation of ethical codes within the profession.

## 1.6 Review Material

### *1.6.1 Key Terms and Concepts*

Accreditation
Adversarial system
Anthropometry/Bertillonage
Certification
Civil law
Criminal law
Criminalistics
Cross-examination
Defendant
Direct examination
Fallibilism
Felony
Finder of fact
Generalists
Grand jury
Jurisdiction
Locard's exchange principle
Misdemeanor
Plaintiff
Private laboratories
Prosecution
Prosecutorial bias
Public laboratories
Scientific method
Specialist
Subpoena
Trier of fact
*Voir dire*

### *1.6.2 Review Questions*

1. The systems of science and the law have two different purposes. Summarize these in your own words.
2. What type of incident was the most important in driving the initial development of forensic science?
3. What is the difference between a forensic generalist and a forensic specialist? Name two forensic specialties that you have heard of.
4. List the forensic scientists that were involved in the early development of fingerprints. What made fingerprints so important to forensic science at the turn of the 20th century?
5. What would you expect to be the biggest disadvantages to the Bertillon system of identification of individuals?
6. What is the fundamental characteristic of an adversarial system such as the law?

7. What are the differences between public and private forensic laboratories?
8. What is the difference between accreditation and certification?
9. What process is used by the trier-of-fact and the courts to determine if a scientist is qualified to offer expert testimony in a given case?
10. You are a new fingerprint examiner hired to work in a forensic laboratory. You have been trained in fingerprint evaluation and have a degree in forensic science. One day, your supervisor brings you a case file and asks you to see if you agree or disagree with his identification of a fingerprint. You study the case and come to the conclusion that the senior analyst was incorrect. When you discuss this with him, he becomes angry and refuses to reconsider his findings. What do you do, and why?

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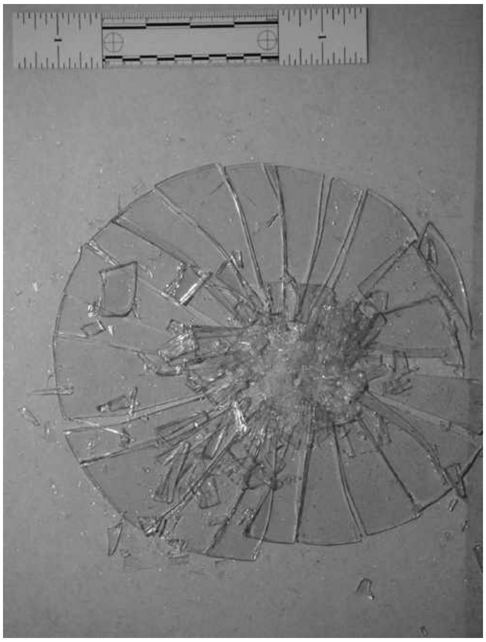
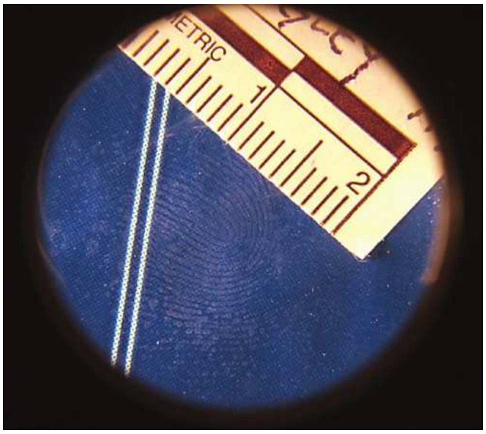
# 2

# Evidence: Origins, Types, and Admissibility





## Chapter Overview

Evidence can be tangible things such as a bloody shirt, a tiny fiber on a baby blanket, a blood sample, or a fingerprint. These are all examples of physical evidence, and we will spend most of the rest of this book talking about different types of physical evidence and the scientific techniques used to evaluate it. Testimony can also be considered to be a type of evidence; forensic scientists offer their opinions as part of the body of evidence considered by the court. In this chapter, we will explore how things become evidence and how courts decide if an item or testimony should be admitted into the body of evidence associated with a specific case.

# Chapter 2
# Evidence: Origins, Types, and Admissibility*

*Linda R. Netzel, Terrence F. Kiely, and Suzanne Bell*

## Chapter Outline



## 2.1 Rules of Evidence

The importance of forensic science to criminal law lies in its potential to supply vital information about how a crime was committed and who committed it. If the information survives the screening function of the **rules of evidence**, it can be accepted as evidence of a material fact in the ensuing trial. Evidence is court-approved information that the trier of fact, typically a jury, is allowed to consider when determining a defendant's guilt or innocence. The admissibility or inadmissibility of information—whether eyewitness testimony, photographs, physical objects, or scientifically generated information such as DNA—is determined by the trial court's application of the rules of evidence. This set of evidentiary rules is basically exclusionary in nature; that is, these rules serve to filter out information presented by either side that may be irrelevant to the factual and legal issues at hand or that violate long-standing prohibitions such as those against the admissibility of hearsay or substantially prejudicial information. The system of rules that constitutes the law of evidence controlling the flow of information in civil and criminal litigation is exclusionary.

* This chapter is based in part on Chapter 13, "The Forensic Laboratory," by Linda R. Netzel, and Chapter 33, "Forensic Evidence," by Terrence F. Kiely, as published in the third edition of this text.

The term **forensic evidence** encompasses two distinct ideas and processes. The *forensic* part refers to the scientific processes through which facts are generated. The manner in which DNA is extracted, tested, and subjected to population analyses serves as a major example. The methodologies of hair, fiber, and fingerprint examination are other illustrations. The area of forensic science encompasses a discrete number of well-known disciplines, whereas the *science* addressed in product liability and environmental civil cases does not lend itself to such finite boundaries. Although there are repetitive areas of scientific focus in civil cases involving chemistry, pharmaceuticals, biology, and mechanical or electrical engineering, there is much less of an opportunity to discuss the general outlines of acceptable methodology in the arena of civil law. In contrast, the criminal courts do require the forensic sciences to provide broad reviews of their methodology. Nonetheless, the legal concerns are basically the same.

The *evidence* part of the concept of forensic evidence refers to a distinct set of procedures that are unique to the litigation process. These legal procedures are separate and distinct from the scientific processes that serve as the basis for the decision to admit or exclude evidence, including forensic evidence in criminal cases.

How does forensic evidence differ from other evidence? Forensic science involves the application of scientific theory accompanied by laboratory techniques involving a wide variety of traditional academic natural sciences, such as anthropology, DNA analysis, and geology. Certain disciplines associated with forensic science are nontraditional in nature, such as footwear impression techniques or fingerprint analysis. Many disciplines utilize the comparison microscope and other microscopy instrumentation with superb results in the investigation and prosecution of crime. It is important to remember that the reason for using the forensic sciences is to generate forensic evidence. That is the *forensic* part of forensic evidence. The intent is to get to the evidence part. All of this carefully gathered information is generated to meet the goal of establishing material facts at or before trial, not to demonstrate the latest technological advances or most recent methodologies.

Forensic and other types of evidence are used to reconstruct the events that encompass the crime being prosecuted. Given the rule for speedy trials and other constitutional protections, not the least of which are the rules of evidence, such reconstructions are often a formidable task for prosecutors and defense counsel. Increasingly, circumstantial proof presented in criminal trials comes in the form of forensic evidence.

## 2.2 Admissibility of Evidence

In the previous paragraphs, we have defined evidence and its different forms and goals; however, none of these descriptors directly applies to admissibility. Forensic science and forensic scientists generate data, reports, and opinions that all can be used as evidence, but only if the court allows such evidence to be admitted in the first place. How this decision is reached is a critical aspect of forensic science. A central concept regarding the admissibility of trial information is the prerequisite of a solid supportive foundation for any offer of evidence, especially in instances of scientifically generated data such as firearms, fingerprints, or fiber or hair analyses. A foundation consists of sufficiently supportive information presented to a judge to convince him or her that the proposed witness or item of information has the

**SIDEBAR 2.1. CURRENT EVENTS: JUNK SCIENCE**

One of the most important tasks associated with determining admissibility is the exclusion of what is often called "junk science" or "pseudoscience." This is not as easy as you might expect. One way to distinguish good science from junk science is through the test of falsifiability. Scientific reports or hypotheses should always be presented in such a way that it is easy to test and verify the results. In other words, the results must be falsifiable. We can write equations to describe gravity and then test these with observation and experiment. However, consider another example. Astronomy is a science based on equations, data, and observation. Any theory put forth can be tested by other scientists. Astrology is a belief system that states that the position of the stars on your birthday influences your life. This is not a falsifiable statement because it is vague and offers no way to conclusively prove or disprove it. While it may be fun to read your horoscope, you likely would not like to be convicted of a crime based on your horoscope. Astrology is inadmissible as scientific evidence.

potential to be true, and hence a jury could reasonably determine that it is or is not true. How the judicial system has made this determination has evolved as significantly as scientific capability has. As we go through this section, keep in mind that we are focusing on practices and procedures used in the United States; different countries have different systems.

### *2.2.1 Admissibility Hearings*

Before any scientific evidence is presented before a court, it must be determined to be admissible. **Admissible evidence** must be reliable and relevant to the case at hand, and for scientific analysis, the court must be assured that the methods used are scientifically acceptable and reliable (see Sidebar 2.1). The intent of admissibility proceedings is to prevent the introduction of results obtained using poor science or pseudoscience, or admission of evidence that has no bearing on the case. Admissibility hearings provide a way for new scientific test methods to be introduced and accepted as viable tools in forensic science. If required, these hearings are held separately from the case presentation. The standards that courts use to determine admissibility of evidence vary among the jurisdictions, and we will discuss the most important ones.

Those jurisdictions following the "***Frye* standard** (*Frye v. United States*) require that new methods be generally acceptable to a significant proportion of the scientific discipline to which they belong. For example, new chemical tests would have to be generally accepted as reliable among most analytical chemists. Jurisdictions that follow the Federal Rules of Evidence and the *Daubert v. Merrell Dow Pharmaceuticals* decision use more flexible guidelines. Essentially, under *Daubert*, the trial judge is responsible for determining if the scientific evidence is useful and relevant and that the expert presenting it is qualified to discuss the results and offer an opinion. The judge must also determine if the testing method rests on a reliable and reasonable scientific foundation. Such hearings are referred to as ***Daubert* hearings**. We will look at these three approaches in more detail. Both the Frye and Daubert methods were articulated by court cases.

### 2.2.2 The Frye Decision and Frye Standard

In 1923, the D.C circuit court of appeals (293 F. 1013 (D.C. Cir 1923)) handed down the first ruling that applied to the modern era of forensic science. The ruling was a rejection of the validity of the polygraph (lie detector) test, which stated in part:

> Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in the twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.

This ruling led to criteria referred to as **general acceptance** that governed the admissibility of scientific evidence in many jurisdictions. However, the ruling became more problematical as scientific advances continued and scientific disciplines became more compartmentalized. As this occurred, the idea of general acceptance within a particular field became more difficult to obtain or define. Furthermore, the criteria set forth in *Frye* were seen as restrictive of innovative techniques that might be known and accepted to only to a small portion of scientists within any given discipline. This limitation would become evident as science advanced rapidly after 1923.

### 2.2.3 The Federal Rules of Evidence

From 1923 until the late 1960s, there was little change relative to the admissibility of scientific evidence. However, it became obvious that the Frye standard was not sufficient in an era of incredible scientific advancement. In 1969, a draft of what would become the **Federal Rules of Evidence** was put forth by a committee formed at the request of the U.S. Supreme Court. After delays and revisions, the Rules were enacted by Congress in 1975, 52 years after the *Frye* decision. Rule 702, "Testimony by Experts," states:

> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise.

While a step forward, the rules did not discuss how a witness was to be qualified as an expert and what specifically the court should weigh in determining qualifications of an expert and the validity of the science or technology in question. The Rules of Evidence apply only to federal jurisdictions, but many other jurisdictions adopted these or similar rules in regard to admissibility. It would be nearly 20 years before the Supreme Court would directly address admissibility in a general way.

### 2.2.4 Daubert Decision (1993)

*Daubert v. Merrell Dow Pharmaceuticals* (113 S. Ct. 2786 (1993)) was a landmark case regarding admissibility. The plaintiffs in the civil case were parents of child born with birth defects. The parents believed that the birth defects were the result of a morning sickness medication taken by the mother during her pregnancy. In these types of cases, scientific evidence is often the critical information in reaching a decision. In their ruling, the Supreme Court stated that under the Federal Rules of Evidence, Rule 702, general acceptance (from the *Frye* decision) is not an absolute requirement for determining admissibility; rather, it is the responsibility of the trial judge to determine if scientific evidence is relevant and reliable. This role assigned to the judge is often referred to as the **gatekeeper**, and the Court offered suggestions for making that determination while leaving flexibility to the judges. General acceptance was one criterion, as were peer review of the technique, standards for the method, validation of the method, potential errors, and testable (and thus falsifiable) theories. The Court had provided judges with a series of suggestions and methods by which the quality of the science and experts could be evaluated before granting admissibility.

### 2.2.5 The Trilogy

The *Daubert* decision was one of three in the late 1990s that significantly impacted the way in which many jurisdictions addressed the admissibility of evidence. The other two cases (*General Electric Co. vs. Joiner* and *Kumho Tire Co. v. Carmichael*) along with the *Daubert* decision constitute what is often referred to as the ***Daubert* trilogy**. In *Daubert*, the concept of the judge as the gatekeeper was firmly established; the other cases built upon that foundation.

The *Joiner* case was a complex civil suit in which an employee sued General Electric, claiming that his cancer was directly attributable to his being exposed to chemicals while working for the company. The plaintiff (Joiner) wanted to have scientific studies on animals admitted to support his case but the court rejected this on the basis that the study in question was not directly applicable to the issue because the study was focused on different chemicals and different exposures than those experienced by Mr. Joiner. This ruling meant that scientific data had to pass the *Daubert* criteria as well as a relevance test before it could be admitted.

The *Kumho* case, also a civil case, centered on the responsibility of the Kumho Tire Company in a fatality that resulted from an accident attributed to tire failure. One of the expert witnesses presented was an engineer, and the court ruled that the testimony offered by the engineer fell under the umbrella of scientific expert. In other words, *Kuhmo* extended the *Daubert* ruling to all experts, not just scientists such as biologists or chemists.

## 2.3 Categories of Evidence

There are many ways to categorize forensic evidence. For example, a piece of evidence such as a fingerprint recovered from a murder weapon can be **inculpatory** or **exculpatory**, meaning that its presence can include or exclude a person as a source and thus tend to incriminate or exonerate him or her. Evidence can also be **direct** or **circumstantial**. Direct evidence is information that establishes directly, without the need for further inference, the fact for which the information is offered. An example would be eyewitness testimony that the defendant fired the fatal shot in a murder prosecution.

It is important to understand that forensic evidence is circumstantial evidence. Circumstantial evidence, which includes the lion's share of evidentiary offerings in U.S. courts, allows the trier of fact to accept as proven a fact for which direct evidence is unavailable by inference from a fact that is directly proven. For example, suppose a defendant's blood is found at a crime scene and linked to him by DNA results. From

***Figure 2.1*** Reconstruction evidence.

this information, we can infer that he was at the crime scene. However, taken alone, the DNA results cannot speak to guilt or innocence in a murder case. More information is required for such a leap; the DNA results are just one part of a larger story. If, for example, his shoes were found to contain traces of soil consistent with the crime scene, this would be another piece of circumstantial evidence.

Evidence can be categorized based on how it is used. **Reconstruction evidence** (Figure 2.1) provides information about the events preceding, occurring during, and occurring after commission of a crime. Reconstruction of a crime scene is particularly valuable in instances where a suspect admits to having been at the scene but did not play a role in the crime. Although scientific principles are applied, reconstruction of a crime involves observation, logic, experience, and evaluation of statements by key witnesses. This may provide the greatest opportunity for the criminalist and detective to work as a team in solving a crime. As an example, bloodstain pattern analysis, the topic of Chapter 4, can provide strong reconstruction evidence. The interpretation of bloodstains is generally very useful in cases where an individual claims to have aided or assisted an injured or dead person as an explanation for blood found on his or her person or clothing. Bloodstain evidence may also be of great assistance in determining whether a person died as a result of suicide, homicide, or accident.

The tools used for reconstructing a crime scene will generally locate evidence that can then be used to associate or disassociate a suspect to a crime. Hairs, fiber, blood and other body fluids, paint, glass, firearms, bullets, fingerprints, and other imprint evidence are all examples of **associative evidence**. These items are considered of unknown or questioned origin until a comparison is made to a known standard or **exemplar**. A standard may be collected from a victim, suspect, witness,

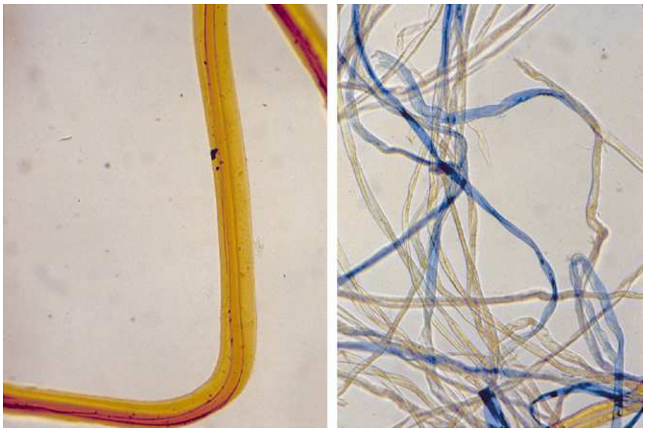


***Figure 2.2*** Evidence with class characteristics.

or investigator. Although the examination of associative evidence is the primary focus of a forensic laboratory, the ability to reconstruct a crime is necessary to determine the significance of associative evidence. Associative evidence can be further subdivided into class and **identification evidence**.

Another way to look at forensic evidence is through the conclusions that the evidence facilitates. From this perspective, forensic evidence comes into court in two basic forms: (1) **class-characteristic** evidence (Figure 2.2), which does not reference a particular suspect, and (2) **individual characteristics** (Figure 2.3) that do, inferentially, associate a particular individual with the commission of a crime. Testimony that the pubic hairs found on a rape–homicide victim came from a Caucasian male or that shell casings found at the scene came from a certain make and model of firearm are two typical examples of class-characteristic statements. The second type of potential testimony generated by forensic science is the individual characteristic or matching statement that serves to link data found at the crime scene to a particular defendant. Testimony finding that court-ordered pubic hair exemplars obtained from the defendant are consistent in all respects to the hair found on the victim or that fibers found on a victim's clothing are consistent with fibers from a defendant's jacket provides two examples.

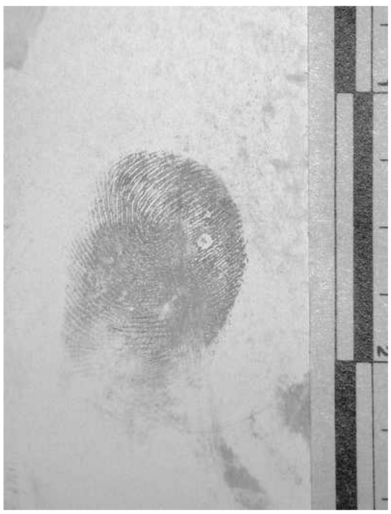


***Figure 2.3*** Evidence with individual characteristics.

Class-characteristic statements garnered from forensic analyses illustrate the great value in a criminal investigation of statements drawing contextual lines for subsequent attempts to link a particular suspect to a crime scene, especially by excluding other potential suspects. A goal of forensic science is to link a potential offender to a crime scene by way of testimony as to individual characteristics, connecting a physical sample obtained from the suspect with a similar sample from the crime scene. The exclusionary potential of class or individual forensic findings is equally important, as it can eliminate a suspect or void a conviction based on the lack of adequate forensic evidence. Class-characteristic evidence is not considered unique and is part of a limited class along with other potential members (Figure 2.2). Identification evidence, on the other hand, positively provides for identification of the source of questioned evidence (Figure 2.3). When comparing evidence of both types, the examiner must convey the meaning or significance of the results in a written report.

When examining class-characteristic evidence, the examiner must make all reasonable attempts to distinguish questioned samples from known standards. The result may be that the questioned sample is indistinguishable from the known standard, that it does not match the known standard, or that the comparison is inconclusive. Conclusions regarding comparisons of class-characteristic evidence are limited. The questioned sample, even when indistinguishable from the known, cannot be said to be from that particular standard to the exclusion of all others. For example, if green carpet fibers are indistinguishable from the carpet of a suspect's car, this evidence does not exclude all similar carpeting as the source of the fibers.

Individual characteristic evidence includes fingerprints, DNA profiles, some impressions, and evidence of fracture matches. Courts and juries have long accepted fingerprints as evidence of identification, although statistics regarding the significance of the match are generally not provided. Conversely, the use of DNA to identify individuals has been highly scrutinized and the forensic laboratory must provide statistics demonstrating the significance of the genetic profiling results. By examining a number of genetic locations, the frequency of occurrence of a genetic profile will become vanishingly small. Fracture matches are made when an unknown fractured piece that may have come from an automobile grill is matched to a known piece by comparison of the fractured edges of both samples.

Whether the evidence is of the class or identification type, it is important that a scientist understand and acknowledge the significance of the final result. Determining the significance may include consideration of the location of the evidence, the type and quantity of evidence, the condition of the evidence, and crime scene reconstruction. If an item of evidence is identified as coming from a suspect, the suspect is associated with the evidence but that does not prove that he or she committed the crime. The criminalist must responsibly report his conclusions in a timely and consistent manner and let the trier of fact, judge or jury, determine guilt.

Finally, we can categorize evidence by its scientific grouping. In many cases, these categories overlap, but this approach is often useful for general descriptive purposes. An example in which many types of evidence was important in a case is given in Case Study 2.1. These groups include the following:

- *Biological evidence*—Typically, human (or occasionally other) tissues used for identification and individualization of human tissues constitute the focus of forensic biology. Conventional serology, such as ABO blood grouping (Figure 2.4) has largely been replaced by DNA testing. Current DNA technology is primate specific, utilizes minimal samples, and allows for identification of individuals. This type of evidence is described in Chapters 8 and 9.

## CASE STUDY 2.1

A woman visiting a large metropolitan city for a professional conference was attacked at the door of her 17th-floor hotel room, struck on the head, and forced into her room. Once inside the room, the assailants bound her hands and began searching the room for property. The victim overheard an assailant say they only had one condom. She was then raped by both assailants and sodomized by one. After the sexual assaults, the suspects washed the victim with several towels and washcloths and wiped the surfaces of the room. They bound her legs with cut-up bed sheets and covered her with the mattress of the bed. Before leaving, they stole her cellular phone and a couple hundred dollars in cash from her purse. The victim was able to free herself and immediately ran to an adjacent room to dial 911. The police responded and took her to a hospital for medical attention and a rape examination. Her clothing and evidence of the sexual assault were collected from her body.

Numerous items of value were collected from the crime scene. The sheets used as bindings, the towels used to wash the victim, a condom wrapper, the victim's purse, and several fingerprint lifts were collected. The used condom was found floating on the surface of the toilet bowl water. Transfer bloodstains were observed on the bindings, particularly in the areas where knots had been tied. When the knots were untied, foreign hair and a piece of chewed gum were located. Blood was also found on the victim's purse. No semen was located on the towels or sheets. Additional foreign hairs were found. A partial fingerprint was developed on the condom wrapper. Examination of the rape kit revealed the presence of semen on the rectal samples only. Also, condom trace evidence was found on the vaginal samples but not on the rectal samples.

The chewed gum, rectal samples, and blood lifted from several items resulted in a DNA profile of one male. Several attempts to detect a DNA profile on the condom produced the victim's profile and a partial profile of the second assailant. The fingerprint evidence matched the suspect whose DNA was found on the condom. Questioned hair was also consistent with the second assailant. All of this evidence was crucial to the prosecution because the victim was unable to identify her attackers.

One suspect was quickly apprehended after he used the victim's cellular phone to make several calls before he sold the phone. The tracing of the cellular phone calls and subsequent alerting of the police by the phone purchaser resulted in apprehension of the suspects. Collectively, the physical evidence identifying the suspects was overwhelming but both suspects chose jury trials. The law precluded trying the defendants together so all of the evidence, including the victim's testimony, had to be presented twice. Both trials resulted in convictions on burglary, kidnapping, forcible rape, forcible sodomy, and sexual abuse charges. The defendants were given multiple life sentences.

- *Chemical evidence*—Primarily, forensic chemistry deals with seized drugs, toxicological samples, materials chemistry, and explosives. Chemical evidence is discussed in Chapters 10, 11, and 12.
- *Trace evidence*—As we noted in the last chapter, Locard's exchange principle basically states that, whenever two objects come in contact with one another, a transfer of material will occur. The transfer may be tenuous, but

***Figure 2.4*** Blood identification.

it will certainly occur. In other words, a suspect will leave something at and take something away from a crime scene. Trace evidence is discussed in Chapter 16.

- *Fingerprint evidence*—Two aspects of fingerprinting are generally associated with the forensic laboratory: latent print development and fingerprint identification (see Figure 2.5). The development of latent fingerprints can be accomplished via chemical methods, physical methods (such as powders), and lighting and photographic methods. The method used depends on the latent print and the surface on which the print is located. For example, cyanoacrylate or Super Glue® fuming is commonly used on difficult surfaces such as plastics and firearms. Fluorescent powders may be used to enhance a latent print on a particularly colored surface or for use with an alternate light source. Alternative light sources and ultraviolet photography are used as nondestructive methods of latent print development. Much more information regarding this type of evidence is presented in Chapter 13.
- *Impression evidence*—Footwear and tire impressions are examples of impression evidence examined in the forensic laboratory (see Figure 2.6). Impression evidence can provide substantial information, including identification, depending upon the quality of the impression and the number of unique features present. Impression evidence is described in Chapters 14 and 15.
- *Firearm and tool mark evidence*—Considered a type of impression evidence, firearm and tool mark evidence encompasses fired bullets, cartridge casings, and shot shells (see Figures 2.7 and 2.8). A variety of markings or impressions are left on these items when a firearm is discharged, and the markings

***Figure 2.5*** Example fingerprint on watch.


***Figure 2.6*** Example footwear impression.

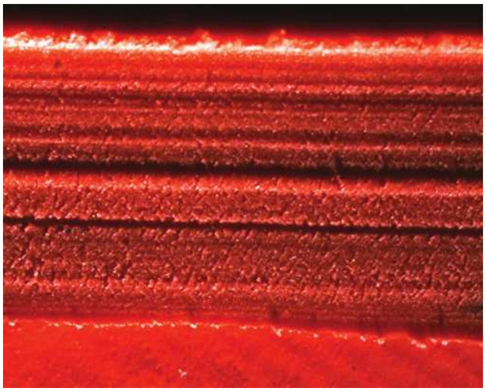


***Figure 2.7*** Example tool mark evidence.

***Figure 2.8*** A color test used to detect bullet holes in fabric.

provide points of comparison to other ammunition fired from the same weapon. Impressions made by tools can also include striation-type markings that share many characteristics of firearms evidence. This type of evidence is discussed in Chapter 14.

- *Questioned documents*—A variety of examinations can be performed in the analysis of questioned documents. The more common examinations include handwriting comparisons, alterations, obliterations, and erasures. Characterization of inks and paper may also provide valuable information. Chapter 17 discusses this type of evidence.

## Chapter Summary

Evidence is the "stuff" of forensic science, and forensic scientists need to understand how it is generated, what it can be used for, how it is analyzed, and how the legal system will decide to admit and use it. The categories of evidence described above are not mutually exclusive, and evidence can fit into many such categories. For example, evidence recovered from a crime scene (reconstruction evidence) might include blood, a weapon, and a fired bullet. The blood, a type of biological evidence, could be used to associate (associative evidence) a specific person (identification evidence) to the crime scene. This proves that the person was at some point present at this location (circumstantial evidence), but alone cannot be used to prove guilt. It is, however, inculpatory evidence. Regardless of how scientific evidence is classified, it must be admitted to a court of law before it can be considered by the trier of fact in any given case. We discussed several standards and court decisions regarding admissibility including the *Frye* and *Daubert* decision standards. Although many jurisdictions have adopted *Daubert*-style rules, some still work the *Frye* standard of general acceptance. One of the most important parts of the *Daubert* decision was that it provided the means by which a trier of fact can evaluate scientific evidence and make a more informed decision regarding its merits and relevance in a given case.

## 2.4 Review Material

### 2.4.1 Key Terms and Concepts

Admissible evidence
Associative evidence
Circumstantial evidence
Class-characteristic evidence
*Daubert* hearings
*Daubert* trilogy
Direct evidence
Exculpatory evidence
Exemplar
Federal Rules of Evidence
Forensic evidence
*Frye* standard
General acceptance
Gatekeeper
Identification evidence
Inculpatory evidence
Individual characteristics
Reconstruction evidence
Rules of evidence

### 2.4.2 Review Questions

1. The rules of evidence are exclusionary. Explain what this means.
2. A bloody towel is recovered at a homicide scene. Describe the *forensic* and *evidence* characteristics of this towel.
3. What kind of foundation would be needed for the towel described in the previous question to be admitted as forensic evidence?
4. What are the key differences between the *Frye* admissibility standards and the *Daubert* admissibility standards?
5. Summarize the key components of each decision in the *Daubert* trilogy.
6. Suppose the towel mentioned in questions 2 and 3 above is found to have a mixture of blood on it. DNA analysis shows that some of the stains are consistent with the suspect and most of it is consistent with the victim. What categories of evidence described in Section 2.3 could this towel belong to?

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# Section I Summary

In this section, we addressed some of the issues and themes that are common to all areas of forensic science. Although most forensic scientists working today specialize in one area such as trace evidence, DNA, or fingerprints, generalists such as Balthazard Gross played a critical role in launching modern forensic science. Perhaps the most famous historical forensic theme is that voiced by Locard, that every contact leaves a trace. Those traces are the evidence that forensic scientists must find, analyze, interpret, report on, and testify about in a court of law. As we learned, the intersection of science and the law is a complex place to work, and forensic scientists must understand concepts of admissibility, expert testimony, and ethics.

## Integrative Questions

1. Compare and contrast the legal system and the justice system. Does the scientific method have elements of the adversarial system in it? Does the legal system have elements of the scientific method in it?
2. Research some of the ethical issues that were brought up with regard to the FBI laboratory in the 1990s. What were these issues and how were they resolved? What role did accreditation play?
3. You are charged with defending a woman charged with murder. The key evidence against her is DNA. Design a list of questions you would ask a DNA expert as part of the *voir dire* process.
4. What ethical codes exist for students at your school?
5. After the Sherlock Holmes stories became popular, there was a surge in public interest in scientific detective work. Compare this to the impact of the television show *CSI: Crime Scene Investigation* today.
6. Look up information regarding the "CSI effect." What is it, what cases has it impacted, and why is the justice system concerned about it?
7. All three cases in the *Daubert* trilogy were civil cases and not criminal cases. Why do you suppose the admissibility of scientific evidence in these cases is so critical and how does it differ from admissibility in a criminal case?
8. How would scientific ethics play a role in determining the admissibility of evidence using the *Daubert* method?

# SECTION II

# The Crime Scene

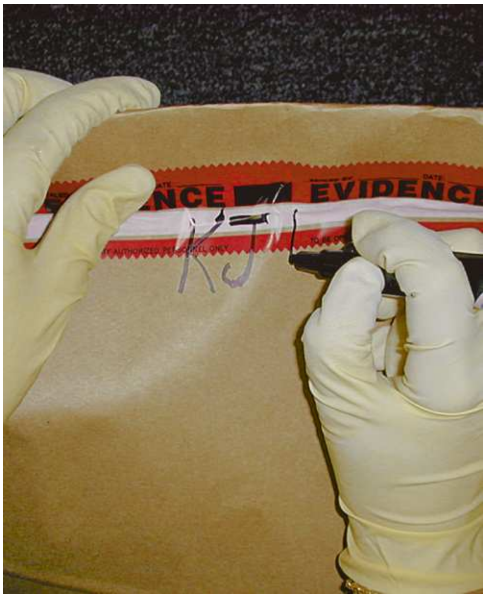
## Section Overview

In the previous section, we established the foundations and fundamentals of forensic science as a discipline. We learned a bit about its history and how science operates within the legal system. We discussed evidence from many perspectives and now we begin our exploration of where evidence comes from. The topics of crime scenes and death investigation are inextricably linked, and we will delve more deeply into that subject in the section to follow. However, it is worth remembering that not all crime scenes involve a death. Crime scenes can be as simple (relatively speaking) as a burglary, as dangerous as a clandestine drug laboratory, or as complex as a multiple murder that takes place in several different locations. Although each scene is unique, the principles that underlie their investigation are consistent. In this section, we will focus on these common elements.

Not all physical evidence arises from crime scenes, but all crime scenes create physical evidence. From nanogram quantities of DNA to artificial intelligence databases capable of identifying latent fingerprints and biological fluids, forensic science and the analysis of very minute quantities of physical evidence have advanced and improved. Crime scene investigation is the starting point for the successful use of physical evidence by the forensic laboratory and the criminal investigator. Successful, high-quality crime scene investigation is a simple but methodical process. It allows the investigators to adapt to the unique characteristics of each scene, yet the overall process follows a set of principles and procedures that adhere to guidelines ensuring that all of the physical evidence is discovered and investigated. The basic crime scene procedures are physical evidence recognition, documentation, proper evidence collection, packaging, and preservation. Once evidence is delivered to the laboratory and testing is completed, scene reconstruction can take place. Every crime scene is unique, and with experience the crime scene investigator will be able to use this logical and systematic approach to investigate even the most challenging scene to a successful conclusion.

This section of the text will present the many aspects of crime scene analysis and processing starting with the fundamentals of crime scenes and their documentation. This will include a discussion of forensic photography, which has evolved at the speed of digital imaging. The second chapter in this section will explore bloodstain patterns, a critical type (but certainly not the only type) of evidence in many violent crimes. Bloodstain patterns can be the key evidence that allows investigators to understand the sequence of events that occurred and to sort out contradictory versions of what happened.

# 3
# Crime Scene Investigation




## Chapter Overview

Any place can become a crime scene. A crime scene may be in a car, in a home, or even under water. Each crime scene is unique because the chain of events that create it is unique, but there are some unifying themes that dictate how a crime scene is studied and processed. In this chapter, we will study crime scenes in general and what information and evidence they can yield. Once a crime scene is created, it immediately begins to change and decay. For this reason, we will emphasize methods of documenting a crime scene to preserve the information for later study.

# Chapter 3
# Crime Scene Investigation*

*Marilyn T. Miller and Patrick Jones*

## Chapter Outline



## 3.1 Defining the Crime Scene

The only thing consistent about crime scenes is their variety. Because of the diversity of possible scenes there are many ways to define or classify crime scenes. First, crime scenes can be classified according to the location of the original criminal activity. This classification of the crime scene labels the site of the original or first criminal activity as the **primary crime scene** and any subsequent crime scenes as **secondary crime scenes**. This classification does not assign any priority or importance to the scene but is simply a designation of sequence of locations. For example, if a person is killed in an apartment and the body is then moved in a car trunk to a remote dump site, the apartment is the primary scene while the car and the dump site are secondary crime scenes.

* This chapter is based in part on Chapter 10, "Crime Scene Investigation," by Marilyn T. Miller, and Chapter 11, "Forensic Digital Photo Imaging," by Patrick Jones, as published in the third edition of this text.

**SIDEBAR 3.1. CAREER PREPARATION AND EXPECTATIONS**

Increasingly, the entry-level requirement for a crime scene processing job is a science degree from a college or university. Ideally, that degree includes education and laboratory training in crime scene processing and related forensic skills. Crime scene analysts can work as part of law enforcement as officers or as analysts in a laboratory. The former is becoming more common, and in these cases crime scene analysts typically do not do a significant amount of laboratory work. Their primary responsibility is crime scene processing and evidence collection. The primary professional organization for crime scene analysis is the International Associate for Identification (http://www.theiai.org/), which certifies crime scene analysts.

A second classification of crime scenes is based on the size of the crime scene. Using this classification, a single **macroscopic crime scene** such as a house may actually be composed of many smaller or **microscopic crime scenes**. For example, a gunshot victim's body dumped in a field represents the following crime scenes within the overall crime scene of the field: the body, the body's wounds, and the ground around the body. The microscopic classification of the scene is more focused on the specific types of physical evidence found in the macroscopic crime scenes. Using the previous example, the microscopic crime scenes are the trace evidence on the body, the gunshot residue around the wound, and the tire tread marks in the ground next to the body. Other descriptions of the crime scene include those based on the type of crime committed (e.g., homicide, robbery, sexual assault), the crime scene condition, the physical location of the crime scene (e.g., indoors, outdoors, vehicle), and the type of criminal behavior associated with the scene. We will learn much more about how criminal behavior and motivation are reflected in a crime scene in Chapter 20.

At the scene, investigators may need to update their assessments as their work progresses. No single definition will work adequately for every scene, and, indeed, there is no need for this as long as the scene is, at the final measure, correctly defined and described. Similarly, the spatial boundaries of scenes may change as the processing continues and investigators take care to avoid establishing immoveable boundaries to any crime scene. The crime expands and changes as the evidence dictates.

## 3.2 Uses for and Information from Physical Evidence in Criminal Investigations

The objectives of any crime scene investigation are to recognize, preserve, collect, and interpret all of the relevant physical evidence at a crime scene with the goal of reconstructing the events that generated this evidence. Often, it is difficult to determine what is pertinent evidence and what is extraneous; this is where the skill and experience of crime scene investigators are invaluable. (For a discussion of career preparation for crime scene investigators, see Sidebar 3.1.) This is always a team effort in which the forensic scientist and crime scene investigators play a role. A forensic laboratory examines the physical evidence to provide the investigator with information to help solve cases. The integration of the crime scene investigation with forensic testing of the physical evidence forms the basis of


***Figure 3.1*** Diagram of crime scene interactions.

scientific crime scene investigation (Figure 3.1). The following are examples of the types of information that can be obtained from forensic testing and examination of physical evidence in a criminal investigation:

- *Linkage of persons, scenes, or objects*—This is the principle behind all crime scene investigations. Recall our earlier discussion of Locard's exchange principle, which states that whenever two objects come into contact there will be a mutual exchange of matter between them. Linking suspects to victims is the most important and common type of linkage made by physical evidence in criminal investigations. For example, a victim of a shooting may not remember exactly where the crime occurred, but evidence recovered from the victim's shoes or clothing could be useful in establishing the location.
- *Investigative leads*—Physical evidence can provide direct information to an investigator; however, not all physical evidence at the crime scene will be directly linked to a suspect. Frequently, the physical evidence will provide indirect information or investigative leads to the investigator. This is an important and significant use of physical evidence in any criminal investigation. Not every crime scene has individualizing physical evidence, such as fingerprints, but every crime scene will have physical evidence that assists the investigator with information, such as a footwear impression's manufacturer or the size and type of shoe worn by the suspect.
- *Information on the corpus delicti*—Determination of the essential facts of an investigation involves the physical evidence itself, patterns of the evidence, and laboratory examinations of the evidence. The red-brown stains in a kitchen may be significant to an investigation but may be more relevant if those stains are bloodstains with DNA matching a victim.
- *Information on the modus operandi*—Criminals repeat behavior, and this particular behavior represents their signature or preferred method of operation. Burglars will frequently gain entry into scenes using the same technique each time, or bombers will repeatedly use the same type of ignition device. The physical evidence they leave behind, once found at the scene, can be used to identify them. This topic will be discussed at length in Chapter 20.
- *Proving or disproving witness statements*—Credibility is an important issue with witnesses, victims, and suspects. The presence or absence of certain types of physical evidence will be useful in determining the accuracy of their statements. Crime scene patterns or patterned physical evidence (e.g., bloodstain patterns, fingerprints, gunshot residue) are especially well suited for determination of credibility.
- *Identification of the suspect(s)*—Forensic examination is a process of recognition, identification, individualization, and reconstruction. Identification of a suspect may be accomplished by matching a recovered latent fingerprint to a fingerprint in a database or from matching a DNA profile of a tiny bloodstain to a profile in a database. We will discuss fingerprints in Chapter 13 and DNA typing in Chapter 9.

- *Identification of unknown substances*—As above, the identification of unknown substances is a common use of physical evidence. Identification of white powders as controlled substances or poisons such as anthrax are examples.
- *Reconstruction of a crime*—This is the final step in the forensic examination process. The crime scene investigator is frequently more interested in how a crime occurred than in identifying or individualizing the evidence at the scene. At this point, the "how" of a crime scene is more important than the "who" of the crime.

## 3.3 General Crime Scene Procedures

### *3.3.1 Scene Management*

The four distinctive but interrelated components of **crime scene management** are (1) information management, (2) manpower management, (3) technology management, and (4) logistics management. Deficiencies, negligence, or overemphasis of any one of these components will imperil the overall crime scene investigation. These components are all based on the fundamental need to maintain good and ongoing communication among all personnel throughout the entire investigation process. The components of crime scene management and the need for continual communication have resulted in some choices for appropriate crime scene investigation models. Each model has its advantages and disadvantages based on the allocation of personnel and resources, training and expertise, crime rates, types of crimes, jurisdictional issues, and the support services available. Details are provided in Table 3.1

**TABLE 3.1**
**Crime Scene Investigation Models**

| Model Type | Description | Advantages | Disadvantages |
|---|---|---|---|
| Traditional | Use of patrol officers and detectives as crime scene technicians | Useful if resources and demand are relatively low | Minimal experience and time commitment conflicts with regular duties |
| Crime scene technicians | Specially trained, full-time civilian personnel | Continuity, specialization, scientific/technical training | Minimal investigative experience, lack of a global view of investigation |
| Major crime squad | Full-time, sworn officers | Primary assignment, increased experience | Depletion of investigative resources due to transfers out of unit, only major cases handled |
| Lab crime scene scientist | Laboratory scientists | Superior technical and scientific skills, knowledge of current methods | No investigative experience, depletion of laboratory resources |
| Collaborative team | Use of police officers, technicians, lab personnel, medical examiners, and prosecuting authorities | Advanced scientific, technical, and investigative resources; shared responsibilities | Extensive resources and comprehensive procedures required, with continual communication |

### *3.3.2 First Responding Officer*

The **first responding officers** to a crime scene are usually police officers, fire department personnel, or emergency medical personnel. These first responders are the only people to view the crime scene in its most original or pristine condition. Their actions at the crime scene will form the basis for successful or unsuccessful resolution of the investigation. They must perform their duties, but they should always keep in mind that they are part of the beginning effort to link victims to suspects to crime scenes. They must never destroy that link. It is imperative that they gain experience and receive continual training or education.

Ideally, the first responders will maintain an open and objective mind when approaching the crime scene. Upon arrival at the scene, safety is a primary concern for themselves and the victim. Once the scene or the victim is safe then the first responders must begin to thoroughly document their observations and actions at the scene. As soon as possible, the first responders should initiate **crime scene security** measures. The duties of first responders include the following:

- Assist the victim and prevent any changes to the victim.
- Search for and arrest the suspect if that person is still on the scene.
- Detain any witnesses. If possible, keep the witnesses separated to preserve their objectivity. Do not take them back to the scene if at all possible.
- Protect and secure the crime scene. Begin taking crime scene security measures by using barrier tape, official vehicles, or other means, as required. Establish a crime scene security log to record any persons who enter or exit the crime scene and limit access to those who truly need it. This helps prevent contamination of the scene with materials brought in after the crime has occurred.
- Document all movements, alterations, or changes made to the crime scene and pass this information to crime scene investigators.

### *3.3.3 Crime Scene Survey*

Once the crime scene investigator has arrived at the crime scene and scene security has been evaluated, the preliminary scene survey, or **walk-through**, is performed. The crime scene investigator and the first responder will usually do the scene survey together. The lead investigator or detective, if available, can also benefit from the scene survey. Often, digital images are collected. The survey is the first examination or orientation of the crime scene by the crime scene investigator, and the following guidelines should be followed:

- Use the walk-through as a mental beginning for a reconstruction theory that can and should be changed as the scene investigation progresses.
- Note any transient (temporary) or conditional (the result of an action) evidence that might be present and requires immediate protection or processing.
- Be aware of the weather conditions, and take precautions if adverse weather is anticipated.
- Note any points of entry or exit and paths of travel within the crime scene that may require additional protection. Be aware of any alterations or contamination of these areas by first responder personnel.

- Briefly record initial observations of the answers to who, what, where, when, and how questions. This is not an appropriate time for a detailed description of the scene.
- Access the scene for personnel, precautions, or equipment that will be needed.
- Notify superior officers or other agencies as required.

## 3.4 Crime Scene Documentation and Forensic Photography

Once the crime scene has been evaluated by the preliminary scene survey, the crime scene's condition must be recorded or documented. This is perhaps the single most important task of the crime scene investigator. Given that crime scenes are transitory and begin to change the instant after they are created, it is essential to have a permanent record of the scene as it was before processing. The purpose of crime scene documentation is to permanently record the condition of the crime scene and its physical evidence. It is the most time-consuming activity at the scene and requires the investigator to stay organized and systematic. Problem-solving skills, innovation, and originality will also be needed. The four major tasks of documentation are (1) note taking, (2) videography, (3) photography, and (4) sketching. All four are necessary and none is an adequate substitute for another; for example, notes are not substitutes for photography and video is not a substitute for sketching. Each tool must be applied when and where needed to give as complete a record as possible.

### *3.4.1 Digital Imaging and Photography*

One of the most striking changes in crime scene documentation in the past 20 years is the advent of digital imaging, which has replaced traditional film cameras in all but a very few instances. (See Sidebar 3.2 for more about the history of forensic photography.) Digital image technology provides the crime scene investigator with powerful tools for capturing, analyzing, and storing the record of the crime scene and its physical evidence (Figure 3.2). These digital image tools complement the traditional video and still photography used in crime scene documentation. The advantages of digital images include instant access to the images, easy integration into existing electronic technologies, and no need for the often expensive film processing

**SIDEBAR 3.2. HISTORICAL NOTE: THE BEGINNINGS OF FORENSIC PHOTOGRAPHY**

Forensic photography came of age during the killings in London attributed to Jack the Ripper (1888). Photographs of victims and the crime scenes became famous and revealed the brutality of the crimes. Europe was the site of much of the pioneering work in forensic photography, including the early use of what are now called mug shots in Switzerland in the mid-1850s. The growing importance of forensic photography was instrumental in the founding of the Lausanne Institute of Police Science in Lausanne, Switzerland, in 1902. This institute remains a hub of forensic science education throughout Europe and the world.

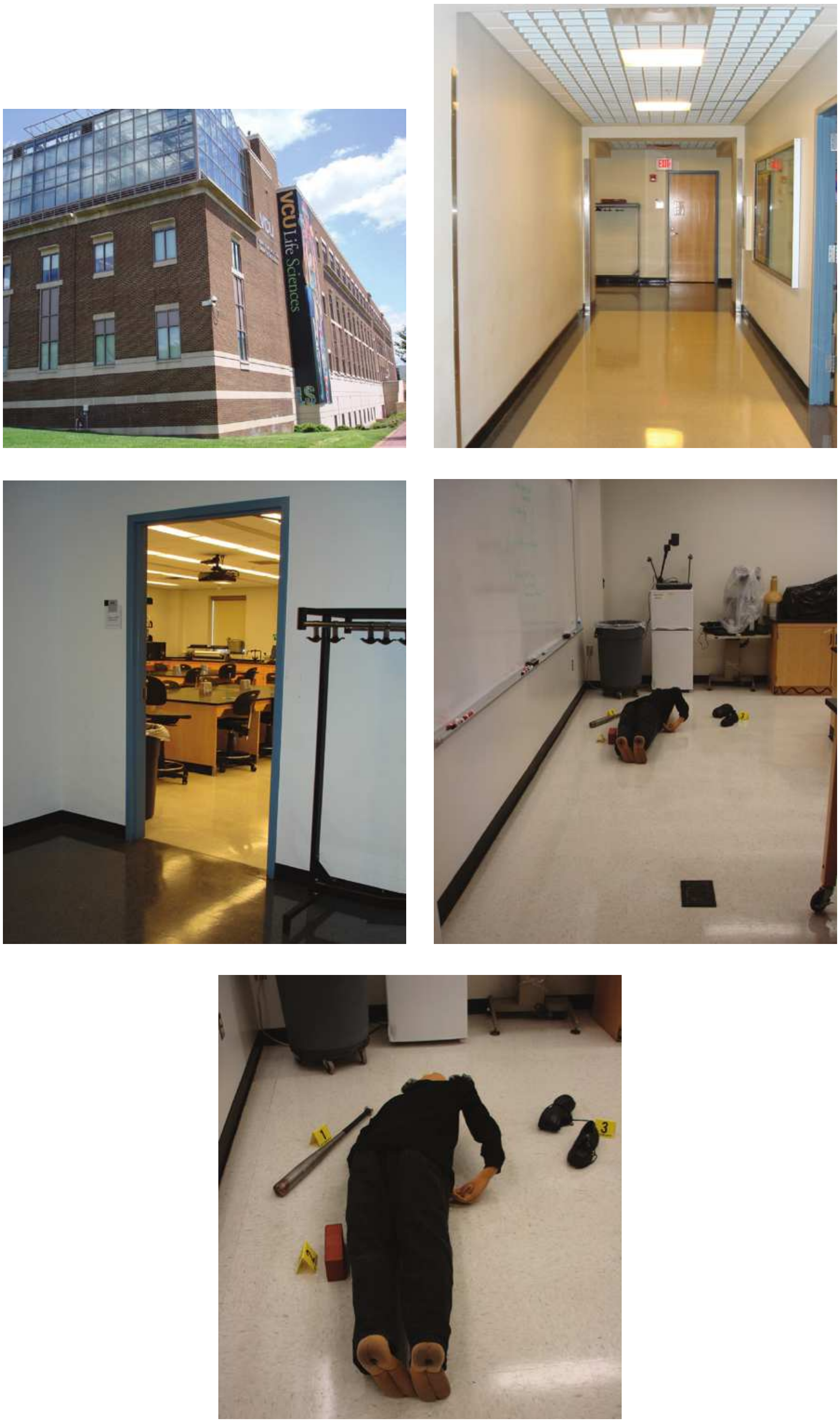



***Figure 3.2*** Capturing, analyzing, and storing the record of the crime scene.

equipment and darkrooms. Some disadvantages of the use of digital image technology are centered on issues of court admissibility due to the ease of image manipulation using programs such as Photoshop®. This problem has become less of an issue as software now generally provides logs and records of any edits that are done to the original. Thus, any changes to a digital image are recorded with that image and are easily retrievable.


***Figure 3.2 (cont.)*** Capturing, analyzing, and storing the record of the crime scene.

The purpose of still photography documentation of the crime scene is to provide a true and accurate pictorial record of the crime scene and physical evidence present. As a result of this documentation, photography is used to record the initial condition of the scene. It provides investigators and others with a record that can be analyzed or examined subsequent to the scene investigation, and it serves as a permanent record for any legal concerns. Photography of a crime scene is normally done immediately following videography of the scene or after the preliminary scene survey. The number of photographs required varies from scene to scene and too many is always better than too few. Table 3.2 summarizes some general guidelines for crime scene photography. Every photograph that is taken at the crime scene must be recorded in a photo log. The log should include the time taken, camera settings used, an indication of distance to subject, the type of photograph taken, and a brief description of the image.

### *3.4.2 Forensic Mapping*

Another forensic application to come out of the digital revolution is the use of imaging technology and mapping technology (GPS) to compile a **crime scene map** that can, in some cases, be rendered in three dimensions. There are several incarnations

**TABLE 3.2**
**Guidelines for Photographing Crime Scenes**

| Type of Photograph | Guidelines for Photographing |
|---|---|
| Overall photographs | Exteriors—Surroundings, buildings and major structures, roads or paths of travel into or away from scene, street signs or survey markers, mailboxes or address numbers; take aerial photographs when possible; photograph before 10 a.m. or after 2 p.m. if possible.<br>Interiors—Use the four compass points or room corners to orient photographs; overlap views; take photographs of doors leading into and out of the structure; use a tripod in low light situations for increased depth of focus. |
| Mid-range photographs | Follow a step-wise progression of views; use various lenses or change the focal length of the lenses to achieve a "focused" view of the individual items of evidence within the original view of the crime scene; add flash lighting to enhance details or patterned evidence. |
| Close-up photographs | Use documentation placards; use flash photography (flash must be detached from the camera); use proper side lighting effects; fill in with a flash when harsh shadows are present; take photographs with and without scales. |
| All photographs | Record in log; use camera settings that achieve good depth of focus; include no extraneous objects such as team members, equipment, feet, or hands; change point of view; be aware of reflective surfaces; when in doubt, photograph it! |

of crime scene mapping hardware, but most include a method of electronic distance determination (also called *electronic data collection*, or EDC), height and slope measurements, mapping capability, and the ability to locate points in three dimensions (including elevation information). The data are downloaded to a program that then reconstructs the data and generates a three-dimensional map of the scene. This equipment is similar to that used by surveyors, and the practice of recording scenes this way is sometimes referred to as *forensic mapping*.

### *3.4.3 Notes*

Effective notes as part of a crime scene investigation serve as a written record of all of the crime scene activities. The notes are taken as the activities are done so they are not subject to memory loss at a later time. A general guideline for note taking is to consider the "**W's**" (who, what, when, where, and why), in addition to the following:

- *Notification information*—Note the date and time, method of notification, and information received.
- *Arrival information*—Note the means of transportation, date and time, personnel present at the scene, and any notifications to be made.
- *Scene description*—Note the weather, location type and condition, major structures, identification of transient and conditional evidence, containers holding evidence of recent activities (ashtrays, trash cans, etc.), clothing, furniture, and any weapons present.
- *Victim description*—In most jurisdictions, the body should never be moved or disturbed until the medical examiner has given approval. Once given permission, then note victim position, wounds, clothing, jewelry, or identification (its presence or absence).
- *Crime scene team*—Note assignments to team members, walk-through information, beginning and ending times, and evidence handling results.

Accurate crime scene note taking is crucial at the initial crime scene investigation, but it is also essential for any subsequent investigations that may follow. These notes must include accurate and reliable measurements of distances, locations, etc.

### 3.4.4 Video Recording Crime Scene

Video recording (**videography**) of the crime scene has become a routine procedure for crime scene documentation. Its acceptance is widespread due to its ability to provide a virtual image of the scene and the increased availability of affordable equipment with user-friendly features such as DVD recording, built-in stability, digital zoom lenses, and compact size. Jury acceptability and expectation have also added to the recognized use of video recording of the crime scene investigations. Videography of the crime scene should follow the scene survey in scientific crime scene investigation. It should not include any members of the crime scene team or their equipment. It should not be narrated and should not contain any audio recording of subjective information at the scene. The following summarizes the process that should be followed for effective videotaping of crime scenes:

- Document the recording by use of a placard that includes the case number, date and time, location, and videographer's name.
- Begin with the scene surroundings. Include roads to and from the scene before taping the general views of the scene itself; use the four compass points as a guide.
- Provide a general orientation of the scene. Videotape the orientation of items of evidence in relation to the overall scene; wide-angle views are especially useful. Do not jump from one location to another; instead, use a smooth transition that encompasses the overall locations of evidence.
- Record the victim's viewpoint. Move to a safe location near the victim and record the four compass points viewed away from the victim.
- Camera technique should include smooth movements; use a tripod or monopod if possible. Use additional lighting for all interior scenes (most camcorders have low-light automatic aperture corrections but additional lighting is suggested). Once videotaping has been completed, review it on the scene and reshoot the scene as needed.
- The original videos are evidence and should not be edited or changed; make copies when needed.

Video recording of crime scenes is a valuable tool for providing an overall, accurate impression of the crime scene that often cannot be accomplished by the other documentation tasks; however, it is never an adequate substitute for any of the other tasks.

### 3.4.5 Sketching the Crime Scene

The final task to be performed during documentation of the crime scene is sketching the crime scene, and a critical aspect of the **crime scene sketch** is obtaining and recording accurate measurements (Figure 3.3). All of the previous tasks for documentation record the crime scene without regard to actual size or measurement of the scene and its physical evidence. Sketching the crime scene assigns units of measurement and provides a proper perspective of the overall scene and the relevant physical evidence identified within the scene.

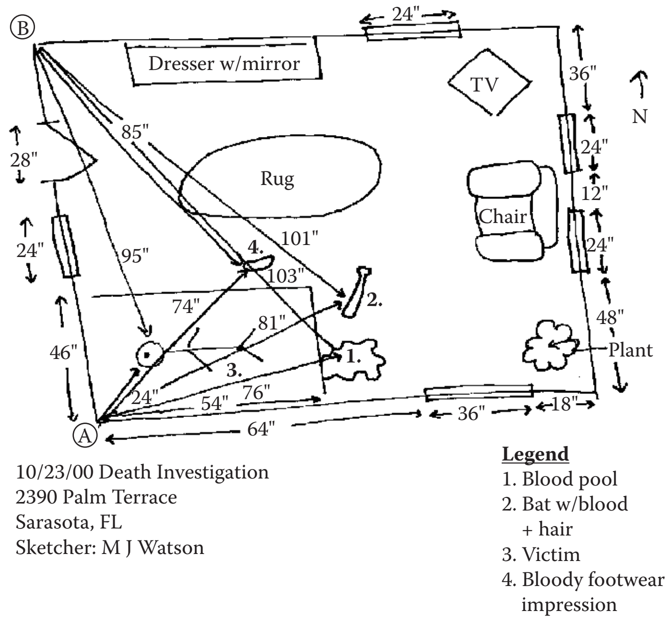



***Figure 3.3*** Rough sketch.

Sketching the crime scene is not difficult but does require some organization and planning by the investigator to ensure that the sketches are accurate. The two basic types of sketches as part of crime scene investigations are the rough sketch (Figure 3.3) and the final or finished sketch (Figure 3.4). Many types of perspectives are used for sketching crime scenes but the two most common are the overhead (or bird's-eye view) sketch and the elevation or side-view sketch. Occasionally, a combination perspective sketch, called a cross-projection sketch, is used to integrate an overhead

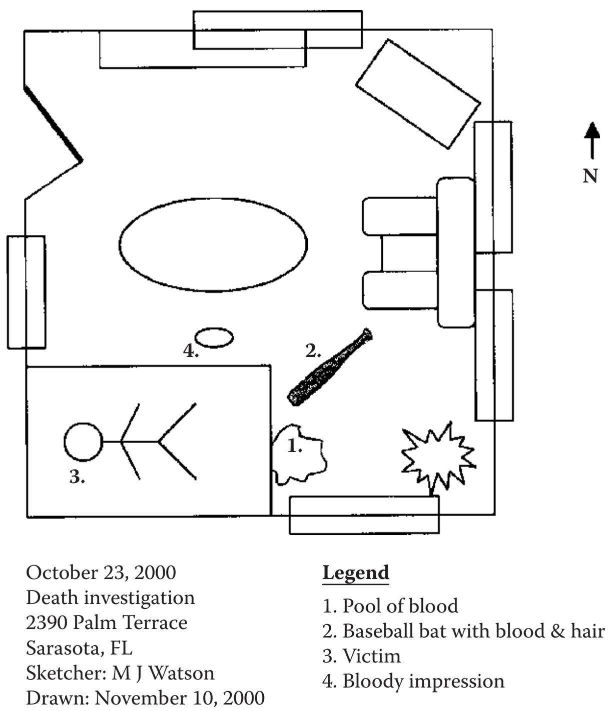



***Figure 3.4*** Finished sketch.

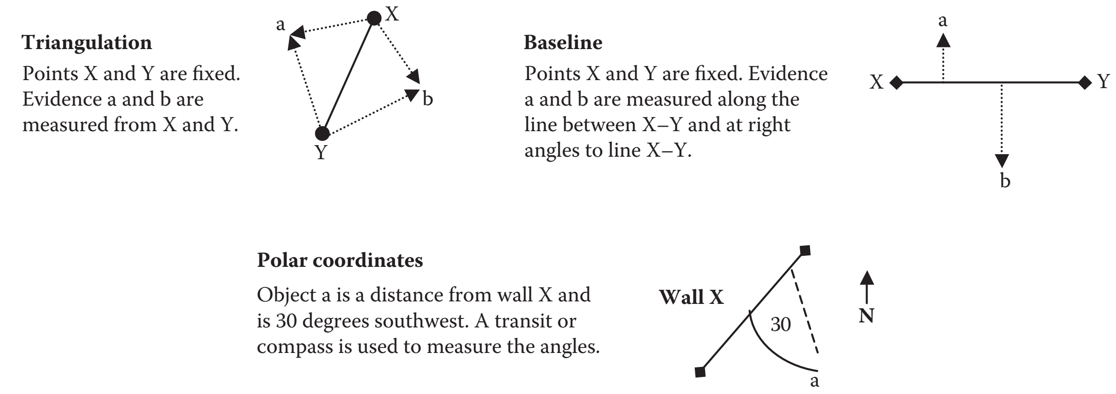



***Figure 3.5*** Coordinates.

sketch with an elevation sketch. Three-dimensional sketches or scaled models are not commonly used but can serve as another form of crime scene documentation. Three techniques are used to obtain measurements for the crime scene sketch: triangulation, baseline (fixed line), and polar coordinates (Figure 3.5). All three techniques identify two starting, fixed points, and all subsequent measurements of the crime scene are in relation to those points. The locations of these fixed points are known or can be precisely determined. This fixed nature is used for subsequent reconstruction. Good fixed points can be building corners, in-ground survey markers, large trees, or recorded utility poles.

All crime scene sketches require their own documentation, including a title or caption; a legend for the abbreviations, symbols, numbers, or letters used; a compass designation; the scale used, if drawn to scale; and the documentation block with the case number, offense type, victim name, location, scene descriptor, date and time when the sketch was begun, and the sketcher's name.

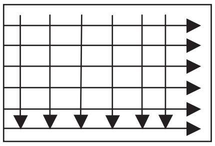
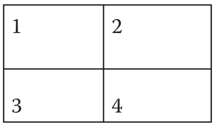
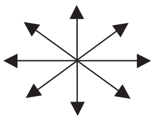
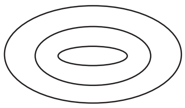
### *3.4.6 Crime Scene Searches*

The preliminary crime scene search is an initial quasi-search for physical evidence present at the crime scene. This search is for obvious items of evidence and is done for orientation purposes before the documentation begins. Once the scene documentation as described above is completed then a more efficient and effective search for less obvious or overlooked items of evidence must be done. This intensive search is done after documentation but before the evidence is collected and packaged. If any new items of evidence are found, then they must be subjected to the same documentation tasks that were carried out earlier.

Crime scene search patterns vary in style, but they share the common goal of giving the search organization a systematic structure to ensure that no items of physical evidence are missed or lost. There is no single method for specific types of scenes. The experienced crime scene investigator will be able to recognize and adapt the search method that best suits the situation or scene. It is important for the crime scene investigator to use that method. Simple reliance on their experience alone and omitting the search step in the investigation will produce mistakes, and significant evidence can be missed.

The most commonly employed search methods are geometric patterns: (1) link, (2) line or strip, (3) grid, (4) zone, (5) wheel or ray, and (6) spiral methods. Each has its advantages and disadvantages and some are better suited for outside vs. indoor

**TABLE 3.3**
**Crime Scene Search Methods**

| Search Type | Geometric Pattern | Information on Use |
|---|---|---|
| Link method | | Based upon the linkage theory; most common and productive method; one type of evidence leads to another item; experiential, logical, and systematic; works with large and small, indoor or outdoor scenes |
| Line or strip method |  | Works best on large, outdoor scenes; requires a search coordinator; searchers are usually volunteers requiring preliminary instructions |
| Grid method |  | Modified, double line search; effective method but time consuming |
| Zone method |   | Best used on scenes with defined zones or areas; effective in houses or buildings with rooms; teams are assigned small zones for searching; often combined with other methods; good for search warrants |
| Wheel or ray method |  | Used for special situations; has limited application; best used on small, circular crime scenes |
| Spiral method |  | Inward or outward spirals; best used on crime scenes without physical barriers (e.g., open water); requires the ability to trace a regular pattern with fixed diameters; has limited application |

crime scenes. Table 3.3 summarizes the various patterns. Before any intensive crime scene search is done, care must be taken to instruct the members of the search party. It is tempting for search party members to touch, handle, or move items of evidence found during the search. Instruct the members to mark or designate the items found without altering the item. In the Old West, firing a shot into the air was a common technique for letting others know that items of evidence had been found. Today, such an approach may not be appropriate, but with proper training, diligence, and care, no evidence will be mistreated during the search of the crime scene. Documentation of the found items must be done before any evidence can be moved or collected; this marks the birth of the item as evidence and the beginning of chain-of-custody procedures.

The practical application of search methods to the crime scene may involve the use of a combination of methods. Searching will frequently require field testing and the use of visualization and enhancement reagents for biological fluids or impression evidence. Also, keep in mind that searching the crime scene should never diminish or interfere with the other functions of the scene investigation, such as proper documentation, collection, and preservation of the physical evidence. Do not avert established crime scene procedures. Protection and preservation of evidence are paramount and can be addressed by restricting the number of searchers and subsequent collectors of evidence. As seen in Sidebar 3.3, in some cases extraordinary measures are required for crime scene searching and processing. Case Study 3.1 describes a more typical scene and how all the elements of crime scene processing come together.

## SIDEBAR 3.3. CURRENT EVENTS: CRIME SCENES IN THE TERRORIST AGE

Crime scenes are no longer confined to relatively small spaces. In the attacks of September 11, 2001, the collapse of the Twin Towers created the largest single crime scene ever processed (Figure S3.3.1). As a mass fatality incident, first responders were concerned first with rescue and then with recovery of human remains. Their activities had to be carried out alongside of crime scene processing using the same principles described in this chapter, albeit on a much larger scale. It was also a scene that integrated many forensic disciplines, from DNA analysts to forensic dentists and forensic engineers. Nearly 3000 people died in the attack.

***Figure S3.3.1*** Largest single crime scene ever processed.

## CASE STUDY 3.1: BLOODSTAIN PATTERNS AND CRIME SCENES

A decomposing body was discovered in a bedroom (see Figure CS3.1.1). The dead man was dressed only in a bath towel and was shot twice at close range with a shotgun. Two television sets in the home were turned on and no signs of forced entry or ransacking of the premises were found. The state police crime scene unit responded. The investigators made sure the scene was secure, spoke with the first responders, proceeded with the preliminary scene survey, documented the scene, and collected and packaged the physical evidence found (Figure CS3.1.2). A male suspect was identified.

Within weeks of the discovery of the body, the investigation focused on two teenaged girls who were friends of the 50-year-old victim. Both of the girls knew the suspect. One of the girls periodically visited and drank alcohol with the victim during the three years before his death. The other girl had been romantically involved with the suspect. At first, both girls denied knowledge of the death; however, when the investigation focused on them, they claimed that the suspect said he had shot the victim. The girl who drank alcohol with the victim gave an even more detailed statement. She said she was an eyewitness to the shooting and that robbery was the motivation.

Her detailed eyewitness account of the shooting specifically stated that the suspect hid behind the door to the bedroom and emerged to face the victim who was entering the bedroom from the hallway, and shot the victim twice. The first shot was in the hallway near the door to the bedroom. The second shot was fired as the victim stumbled forward into the bedroom. According to the eyewitness, the victim then fell in the position in which investigators found his body. The eyewitness said the victim was facing toward the bedroom when he was shot and that the suspect faced toward the hallway entrance to the bedroom. She also told investigators that the suspect held a pillow in front of the shotgun when he shot the victim and that both blasts were fired while the suspect was partially hidden behind the bedroom door.

A not-to-scale crime scene sketch prepared by an investigator showed the locations of various items of physical evidence (Figure CS3.1.3). This sketch reveals that shotgun pellets were found in the bedroom at locations marked 7 through 10. The photographs and crime scene videotape revealed additional shotgun pellets and trajectory marks (Figure CS3.1.4). The crime scene report by the note taker at the scene shows that in the scene investigation no shotgun pellets or wadding were found in the hallway and that all of the pellets were found in the bedroom as documented in the photographs, videotape, and sketch.

The location of these shotgun pellets and the trajectory marks found in the bedroom led the investigators to believe that the shotgun was not pointed toward the hallway, as described by the eyewitness; rather, it was fired into the bedroom from the hallway (Figure CS3.1.3). The positions of the pellets, the trajectory marks, the position of the wadding, and the absence of pellets in the hallway, as documented by the crime scene investigators, contradicted the eyewitness' account of the criminal act.

The crime scene videotape and photographs showed various bloodstain patterns in the bedroom and in the area of the hallway nearest the bedroom (Figure CS3.1.4). The bloodstain patterns were consistent with wounds

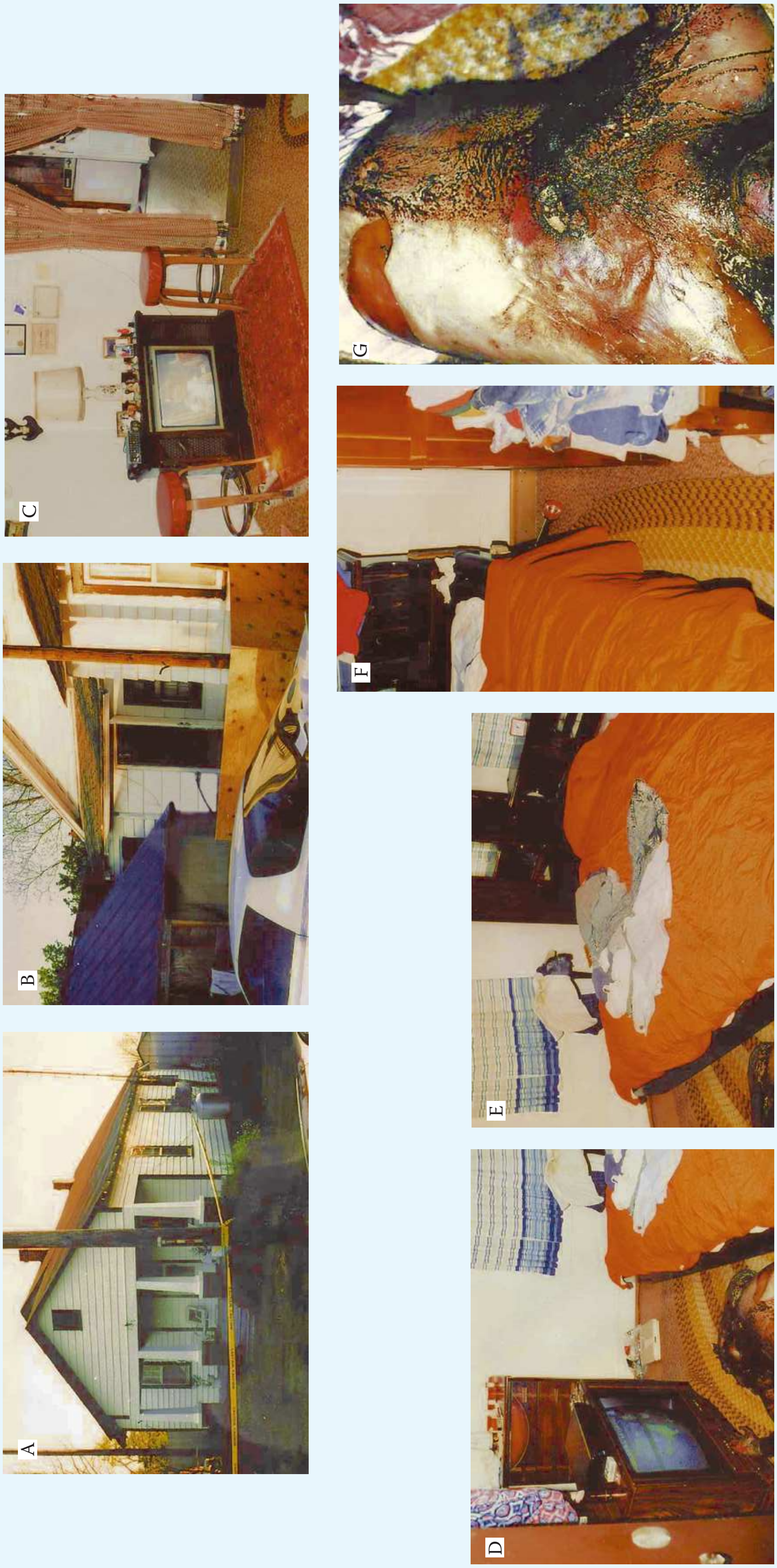
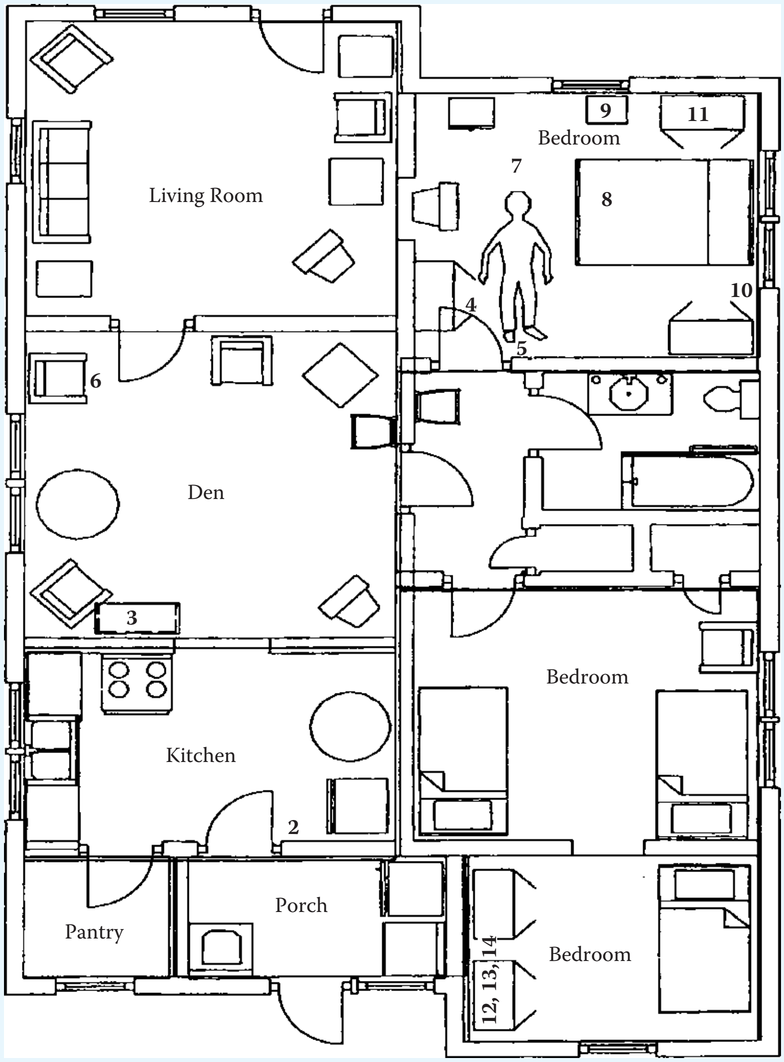



***Figure CS3.1.1*** Photographs of crime scene.

similar to those suffered by the victim. Their documented locations indicated that the victim was standing in the bedroom facing the door into the hallway when shot. Also, documentation of the bedroom door showed no bloodstains. If, according to the eyewitness, the victim received his chest wound as he entered the bedroom and the shotgun was fired from inside the bedroom toward the hallway, then bloodstains should have been present on the door, the floor around the door, and the door frame opposite the area where they were found.




**Legend**

2–Bloodstain
3–Wirebound notebooks
4–Pillow
5–Shotgun wadding
6–Fingernail
7–Pellet
8–Pellet
9–Pellet
10–Pellet
11–Two Prescription vials
12–Denim jacket
13–Black pants
14–Remington shotgun

***Figure CS3.1.2*** Crime scene sketch.

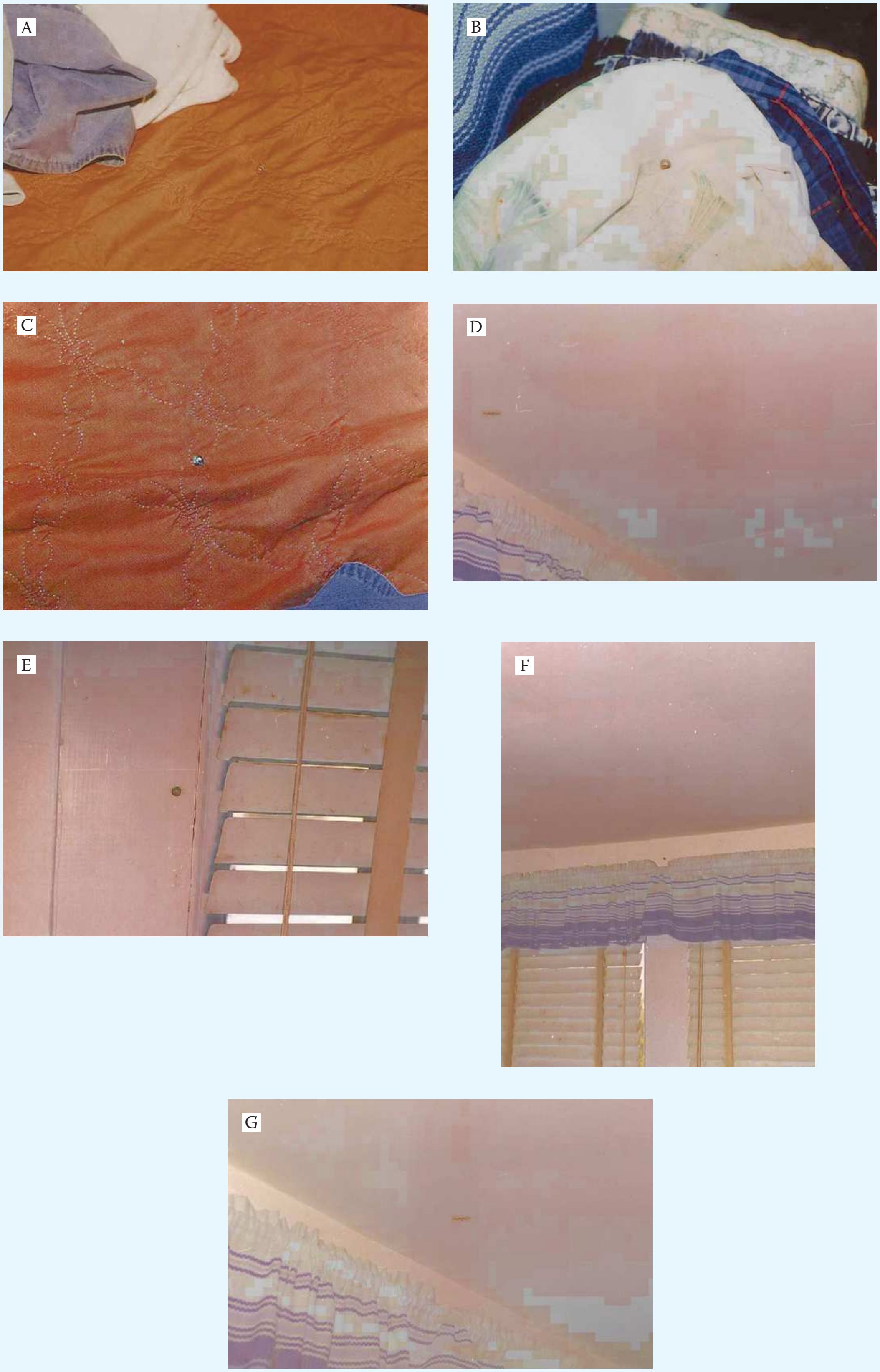



***Figure CS3.1.3*** Photographs taken at crime scene.

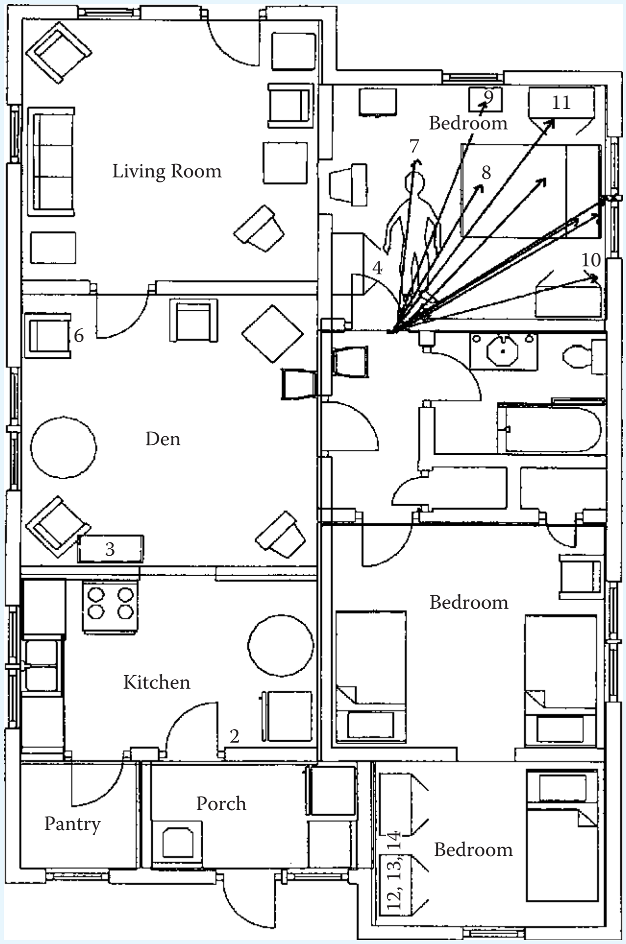



***Figure CS3.1.4*** Trajectory of shotgun pellets.

## 3.5 Collection and Preservation of Physical Evidence

After completion of the crime scene documentation and intensive search of the crime scene for physical evidence, collection and preservation of the evidence can begin. One individual is designated as the evidence collector. This appointment ensures that the evidence is collected, packaged, marked, sealed, and preserved in a consistent manner. There is no rigid order for collection of the evidence, but the collection of some types of evidence, by their nature, should be given priority. Transient, fragile, or easily lost evidence should be collected first. Some items of evidence within the crime scene may have to be moved or repositioned. If items are moved and new evidence is discovered, then the previously discussed methods of documentation must be performed immediately. It is difficult to generalize about the collection of physical evidence. Different types of physical evidence will require specific or special collection and packaging techniques. Because the

*Figure 3.5* Securing trace evidence with paper.


*Figure 3.6* Outer containers.

various chapters in this book discuss the individual types of evidence along with their associated specific collection techniques, only general collection guidelines are presented here.

Most items of evidence at the crime scene will be packaged into a primary container that is then placed inside a secondary container. Druggist's folds are especially well suited as primary containers for trace evidence collection and packaging. Large pieces of paper can be folded around larger items to secure trace evidence in place (Figure 3.5). These folds are then placed inside outer containers such as envelopes, packets, canisters, paper bags, or plastic bags (Figure 3.6). The outer containers are then completely sealed with tamper-resistant tape. The outer container should be marked with information about the item, identification of the collector, the date and time when the item was collected, and the location where the item was found. The sealing tape or evidence tape should completely cover the opening of the outer container. It is marked with the initials of the collector and the date and time of collection (Figure 3.7). It is a good idea to have a wide variety of packaging containers, sealing materials, and markers available at the crime scene.


***Figure 3.7*** Initials of collector, date, and time of collection.

Most items of evidence are solid and can be easily collected, stored, and preserved in the above manner. Liquid or volatile items of evidence should be placed in airtight, unbreakable containers. Wet, moist, or living biological evidence can be temporarily packaged in airtight containers. Such evidence should be allowed to air-dry in a controlled environment and then be repackaged with the original containers in new permeable containers to allow for a drying air flow.

Each item of evidence should be packaged separately to prevent cross-contamination between items of evidence. The containers should be sealed and marked at the time of collection to prevent intermingling of evidence while being moved or transported to other locations. Control standards, alibi standards, and other control samples can be important to an investigation. The crime scene investigator should always be aware of the types of evidence being collected and determine the appropriateness and need for these controls to be collected. These controls are especially important in fire investigations, as well as for trace evidence, blood and body fluid stains, and questioned documents.

## 3.6 Crime Scene Reconstruction

**Crime scene reconstruction** is the process of determining or eliminating the events that could have occurred at the crime scene by analysis of the crime scene appearance, location and position of the physical evidence, and forensic laboratory examination of the physical evidence. It involves scientific crime scene investigation, interpretation of the scene's pattern of evidence, laboratory testing of the physical evidence, systematic study of related case information, and logical formulation of potential scenarios that could produce the evidence at the scene.

Crime scene reconstruction is based on observation, scientific experimentation, and relevant past experiences of the investigator. Its steps and stages, like those in forensic science, follow basic scientific principles, theory formulation, and logical methodology. Reconstruction incorporates investigative information with physical evidence analysis and interpretation and molds them into a reasonable explanation

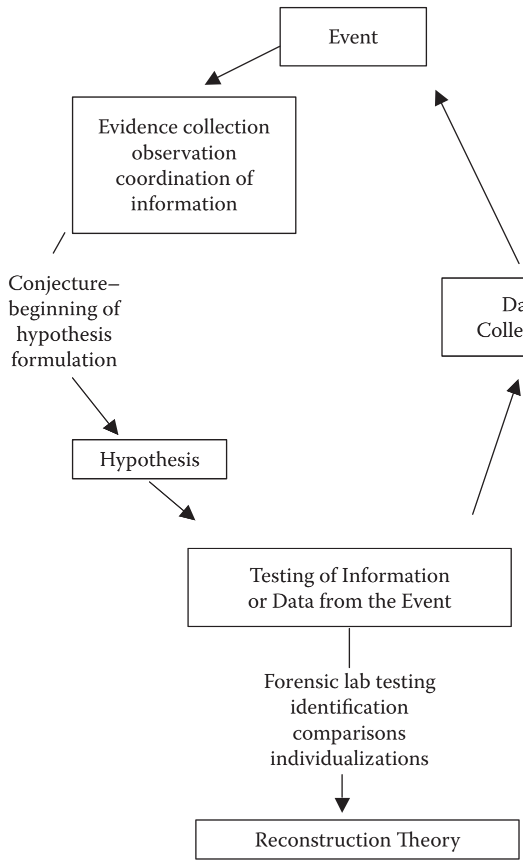



***Figure 3.8*** Fact gathering.

of the criminal activity and its related events. Logic, careful observation, and considerable experience, both in crime scene investigation and forensic testing of physical evidence, are necessary for proper interpretation, analysis, and crime scene investigation.

Crime scene reconstruction is a systematic fact-gathering process (Figure 3.8) based on the scientific method. It involves a set of actions or stages:

- *Data collection*—All of the information and documentation obtained at the crime scene, from the victim or witnesses, is necessary for crime scene reconstruction. Data including the condition of the physical evidence, patterns and impressions, condition of the victim, etc., are reviewed, organized, and studied.
- *Conjecture*—Before any detailed analysis of the evidence is accomplished, a possible explanation of what happened at the crime scene may be developed. It is not fixed or the only possible explanation at this point, as there may be several other possible explanations.
- *Hypothesis formulation*—Additional accumulation of data is based on examination of the physical evidence and the continuing investigation. Scene examination and inspection of the physical evidence must be carried out. Interpretation of bloodstain and impression patterns, gunshot residue patterns, and fingerprint evidence, as well as analysis of trace evidence, will lead to formulation of a reconstruction hypothesis.

- *Testing*—Once a hypothesis has been developed, then additional testing or experimentation must be done to confirm or disprove the overall interpretation or specific aspects of the hypothesis. This stage includes comparison of samples collected at the scene with known standards, as well as chemical, microscopic, and other analyses and testing. Controlled testing or experimentation with regard to possible scenarios of physical activities must be done to corroborate the hypothesis.
- *Theory formulation*—Additional information may be acquired during the investigation about the condition of the victim or suspect, the activities of the individuals involved, the accuracy of witness accounts, and other information about circumstances surrounding the event. When the hypothesis has been thoroughly tested and verified by analysis, the reconstruction theory can be formulated.

Any reconstruction is only as good as the information provided. Such information may come from the crime scene, physical evidence, records, statements, witness accounts, and known data. The information gathering process outlined above and its use during crime scene reconstruction demonstrate the scientific nature of scene reconstruction and allow for its successful use by the investigators. The pattern evidence listed below is especially well suited for utilization in crime scene reconstruction:

- Impression location and position (fingerprints, footwear, tire tread marks)
- Glass fracture patterns (as an indication of direction of force or order of fire)
- Fire burn patterns (to determine points of origin)
- Wound location or dynamics
- Clothing location or damage
- Bloodstain patterns (discussed in the next chapter)
- Shooting investigations (range of fire or gunshot residue analysis)

We will discuss all of these types of pattern evidence in detail in Section 6.

## Chapter Summary

Materials at a crime scene become evidence when they are documented and collected. Scientific crime scene processing is essential to ensure that pertinent evidence is collected and extraneous materials are not and to protect the integrity of the evidence through proper collection and documentation methods. Evidence from a scene requires context; a bloodstain in the kitchen sink next to raw hamburger has a different context than a stain found on the wall of a room in which a homicide occurred. Context is provided by documentation, enhanced by forensic photography and videography. These techniques are supported by sketches and notes, and all of the various elements of documentation are used during crime scene processing. In the next chapter, we will examine a core element of many crime scenes—bloodstain patterns and their analysis. As you read through the next chapter, keep in mind the foundations discussed here, as they are central to meaningful bloodstain pattern analysis and interpretation.

## 3.7 Review Material

### 3.7.1 Key Terms and Concepts

| | |
|---|---|
| Crime scene management | Macroscopic crime scene |
| Crime scene map | Microscopic crime scene |
| Crime scene reconstruction | Primary crime scene |
| Crime scene security | Secondary crime scene |
| Crime scene sketch | Videography |
| Crime scene survey | Walk-through |
| First responding officers | "W's" |

### 3.7.2 Review Questions

1. What are the basic steps of scientific crime scene investigation?
2. List and describe the definitions or classifications of crime scenes.
3. What are the four components of crime scene management?
4. What are the five crime scene investigation models? Describe them and give the advantages and disadvantages of each.
5. Discuss the duties of the first responder at the crime scene.
6. What is the multilevel approach to crime scene security?
7. What are the components or tasks of crime scene documentation? What is the purpose of each?
8. What is the basic process used for photographing crime scenes? Discuss each step.
9. What are the two basic types of crime scene sketches? What are the two types of perspectives used in sketches?
10. Describe and discuss the six types of search patterns used in crime scene investigations.
11. What are the general guidelines for the collection, packaging, and preservation of physical evidence?
12. List and discuss the stages of crime scene reconstruction.
13. What is the purpose of a walk-through?
14. How would you package a single hair recovered from a scene?

## 3.8 References and Further Reading

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Noond, J., D. Schofield, J. March, and M. Evison. “Visualising the Scene: Computer Graphics and Evidence Presentation.” *Science & Justice* 42, no. 2 (Apr–Jun 2002): 89–95.

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Rogers, T. L. “Crime Scene Ethics: Souvenirs, Teaching Material, and Artifacts.” *Journal of Forensic Sciences* 49, no. 2 (Mar 2004): 307–311.

Sant, S. P., and S. I. Fairgrieve. “Exsanguinated Blood Volume Estimation Using Fractal Analysis of Digital Images.” *Journal of Forensic Sciences* 57, no. 3 (May 2012): 610–617.

# 4
# Bloodstain Patterns

## Chapter Overview

When a crime involves violence, there is usually blood present at the scene of that crime. Many times, the patterns of the bloodstains can be studied and used to postulate what events took place to create them. This chapter will discuss bloodstain pattern analysis, how it is performed, and how it can be interpreted and used to reconstruct a crime. All the topics we discussed in the previous chapters apply, including methods of documentation of scenes and collection of evidence. Given the nature of the evidence and its interpretation, it is no surprise that the digital images collected at the scene are particularly critical.

# Chapter 4
# Bloodstain Patterns*

*Stuart H. James, Paul E. Kish, and T. Paulette Sutton*

## Chapter Outline



## 4.1 Bloodstain Pattern Evidence

The geometric analysis of human bloodstain patterns at crime scenes is not a new idea, but it has acquired much greater recognition over the past several decades. **Bloodstain pattern analysis** should be viewed as a forensic tool that assists the

* This chapter is based on Chapter 12, "Recognition of Bloodstain Patterns," by Stuart H. James, Paul E. Kish, and T. Paulette Sutton, as published in the third edition of this text.

**SIDEBAR 4.1. CAREER PREPARATION AND EXPECTATIONS**

Bloodstain analysts represent a range of forensic scientists and crime scene investigators with diverse levels of education. The courts have accepted testimony from individuals with strong backgrounds in chemistry, biology, and physics, many of whom possess degrees in science or forensic medicine. Many of these individuals are employed in crime laboratories or medical examiner offices that have crime scene responsibilities. Crime scene investigators, evidence technicians, and detectives who do not necessarily possess scientific backgrounds have also offered expert testimony. There are also training courses available for bloodstain pattern analysis both at the university and professional levels.

It is worth noting that completion of basic and advanced courses in bloodstain pattern analysis does not imply that an individual is a qualified bloodstain analyst. The formal education must be coupled with years of experience with crime scenes and evidence examination along with regular attendance at scientific seminars. The primary professional organization for the field is the International Association of Bloodstain Pattern Analysts (**IABPA**, http://www.iabpa.org/).

On the job, bloodstain pattern analysts can work with a police agency or a public laboratory, or as a private consultant. Often, these forensic scientists are specialists in crime scene investigation and processing. As such, analysts are frequently on call and can work long and difficult hours, particularly with big cases.

investigator or the forensic scientist to better understand what took place and what could not have taken place during a bloodshed event. In this sense, is it is a form of crime scene reconstruction and can be used as we discussed in the last chapter. The information obtained from the analysis of bloodstain patterns may assist in apprehending a suspect, corroborate a witness's statement, assist in interrogating suspects, and allow for the reconstruction of past events. As with any tool, bloodstain pattern analysis has its strengths and weaknesses. The analysis will only be as valid as the information available and the ability of the examiner performing the analysis. (For a discussion of career preparation for blood stain analysis, see Sidebar 4.1.)

## 4.2 History of Bloodstain Pattern Analysis

The analysis of bloodstains and patterns has been documented in books, journals, and articles for centuries (see Sidebar 4.2), but the science of bloodstain pattern analysis in modern form emerged in the 1800s. Original research and experimentation with bloodstains and patterns was done by the French scientist Dr. Victor Balthazard, whom we met in Chapter 1, and his associates, who presented the material as a paper at the 22nd Congress of Forensic Medicine in 1939. The use of bloodstain pattern analysis as a recognized forensic discipline in the modern era dates back to 1955, when Dr. Paul Kirk of the University of California at Berkeley submitted an affidavit of his examination of bloodstain evidence and findings in the case of *State of Ohio v. Samuel Sheppard*. This was a significant milestone in the recognition of bloodstain evidence by the American legal system. In 2002, the Scientific Working Group on

**SIDEBAR 4.2. HISTORICAL NOTE: THE FUGITIVE**

This famous case became the real-life inspiration for a television series (1963–1967) and for a movie starring Harrison Ford (1993). Dr. Sam Sheppard was convicted of killing his wife in 1954, and the case continued on until 2002. Crime scene investigation and bloodstain patterns provided the key evidence in the case. Sheppard was an osteopathic physician living in a suburb of Cleveland with his wife Marilyn, who was 31 and pregnant on the night of the murder, July 4, 1954. Sheppard claimed to have been asleep on the couch when he awoke to what he thought were his wife's screams. He raced upstairs and found Marilyn on the bed, severely beaten with blood soaked into the bedclothes and spattered all around the room. He told police that he struggled with a bushy-haired man and was knocked unconscious. Sheppard claimed that, after he awoke, he checked his wife's pulse before setting off in pursuit of the killer. He caught the man on the beach and scuffled again, and again was knocked unconscious. He awoke later and called a neighbor, who discovered the body and notified police. While all of this transpired, the Sheppards' young son remained asleep in the room next to his parent's bedroom, where the murder occurred. The way in which the body was found suggested sexual assault, but hints of burglary and drug-related robbery were also discovered. A small green bag was found later on the beach that contained Sheppard's watch and other items. The watch was spattered with blood, suggesting that the wearer was in the room where and when the killing occurred.

Sheppard was convicted and sentenced to life imprisonment. In 1966, the U.S. Supreme Court ordered Sheppard released on the basis that his trial was prejudiced by publicity and errors. The second trial began in 1966, by which time more forensic capability existed. Paul Kirk, a respected forensic scientist of the time, reviewed the evidence, principally blood spatter, and concluded that Sheppard was likely innocent; however, he did not have access to DNA evidence, which would not be available for another three decades. Sheppard was found not guilty and released, but he died in 1970. In the 1990s, Sheppard's son sought further forensic investigation. Forensic profilers, anthropologists, DNA analysts, and crime scene investigators became involved but no clear consensus emerged. Legal actions continued into the new century.

Bloodstain Pattern Analysis (**SWGSTAIN**, www.swgstain.org/) was formed to further develop and standardize bloodstain pattern analysis. This website has a link to a list of the most current terminology used in bloodstain pattern analysis.

## 4.3 Properties of Human Blood

### *4.3.1 Biological Properties*

Fluid blood circulates throughout the body by way of the heart, arteries, veins, and capillaries. It transports oxygen, electrolytes, nourishment, hormones, vitamins, and antibodies to tissues and transports waste products from tissues to the excretory organs. Blood consists of a fluid portion referred to as **plasma** that contains cellular components consisting of red blood cells, white blood cells, and platelets.

When blood has had the opportunity to clot, the fluid or liquid portion of the blood that does not clot is referred to as **serum**. Red blood cells (**RBCs** or **erythrocytes**) transport oxygen from the lungs via the arterial system and return carbon dioxide to the lungs for expiration via the venous system. White blood cells (**WBCs** or **leukocytes**) assist with defense against foreign substances and infection. The nuclei of the white blood cells are the sources of DNA in the blood. **Platelets** are major components of the clotting mechanism of blood. In normal individuals, cellular components comprise approximately 45% of the total blood volume, which ranges in healthy adults from 4.5 to 6.0 liters. A person who loses significant amounts of blood can die by bleeding to death, or **exsanguination**.

### *4.3.2 Physical Properties of Blood*

Exposed human blood is not unlike other commonly encountered fluids. It will act in a predictable manner when subjected to external forces. Blood, whether a single drop or large volume, is held together by strong cohesive molecular forces that produce a surface tension within each drop and on the external surface. **Surface tension** is defined as the force that pulls the surface molecules of a liquid toward its interior, decreasing the surface area and causing the liquid to resist penetration. The surface tension of blood is slightly less than that of water. By comparison, one can appreciate the high surface tension of liquid mercury, which is almost 10 times greater than that of blood. To create spatters of blood, an external force must overcome the surface tension of the blood. The shape of a blood drop in air is directly related to the molecular cohesive forces acting upon the surface of the drop. These forces cause the drop to assume the configuration of a spheroid. Blood, like all fluids, does not fall in a teardrop configuration, even though many artists portray raindrops and other fluids in that manner on television and in newspapers (Figure 4.1).

A passive drop of blood is created when the volume of the drop increases to a point where the gravitational attraction acting on the drop overcomes the molecular cohesive forces of the blood source. The volume required to produce these free-falling drops of blood is a function of the type of surface and the surface area from which the blood drop has originated. For example, research and experimentation have shown that the volume of a passive drop of blood falling through air from a fingertip will be larger than a drop that originates from a hypodermic needle and smaller than a drop originating from a surface such as a baseball bat. The volume of a typical or average drop of blood has been reported to be about 0.05 milliliters (mL)

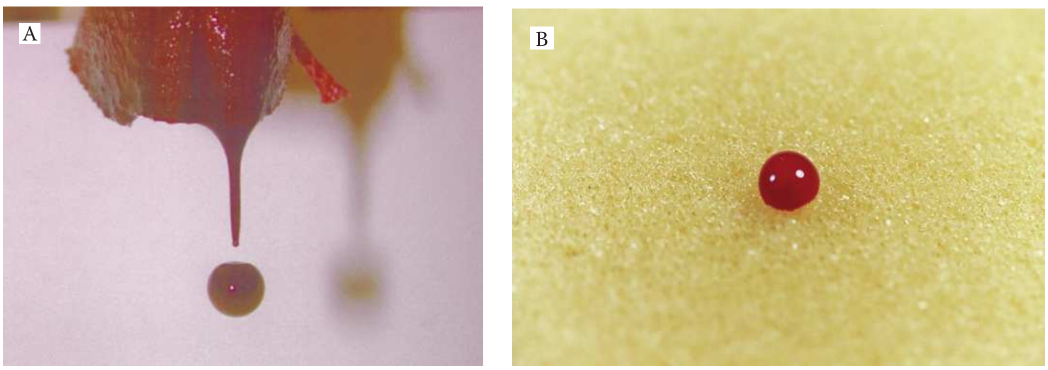


***Figure 4.1*** (A) Spheroid shape of a blood droplet due to the effect of surface tension as it falls through the air after separating from a blood-soaked cloth. (B) Spheroid shape of a blood droplet on cloth due to the effect of surface tension.

(0.0017 ounces), with an average diameter of about 4.5 millimeters (mm) (while in air). These reported measurements can vary as a function of the surface from which the blood has fallen and the rate at which the blood accumulates.

The mutual attraction of the molecules of blood is due to cohesive forces. **Viscosity** is defined as resistance to change of form or flow. The more viscous a fluid, the more slowly it flows. Blood is approximately six times more viscous than water and has a specific gravity slightly higher than water. **Specific gravity** is defined as the weight of a substance relative to the weight of an equal volume of water. These physical properties of blood tend to maintain the stability of exposed blood or blood drops and help them to resist alteration or disruption.

A blood drop falling through air will increase its velocity until the force of air resistance that opposes the drop is equal to the force of the downward gravitational pull. At this point, the drop achieves its **terminal velocity**. One can easily demonstrate that free-falling drops of blood will produce bloodstains of increasing diameters when allowed to drop from increasing increments of height onto smooth, hard cardboard. The measured diameters range from 13.0 to 21.5 mm over a dropping range of 6 in. to 7 ft. Blood drops that fall distances greater than 7 ft will not produce stains with any appreciable increases in diameter. However, in a practical sense, it is not possible to establish with a high degree of accuracy the distance that a passive drop of blood has fallen at a crime scene, as the volume of the original drop is not known.

## 4.4 Formation of Bloodstains and Bloodstain Patterns

### *4.4.1 Target Surface Considerations*

Exposed blood has an invisible outer skin referred to as its surface tension. To create smaller blood droplets or spatter from a volume of blood, this surface tension must be disturbed in some way. Although a single drop of blood falling through air is affected by the forces of gravity and air resistance, these forces do not overcome the surface tension of the blood. No matter how far a drop of blood falls, it will not break into smaller droplets or spatters unless something disrupts the surface tension. One factor in breaking the surface tension of a blood drop is the physical nature of the target surface the drop strikes. Generally, a hard, smooth, nonporous surface, such as clean glass or smooth tile, will create little if any spatter (Figure 4.2A), in contrast to a surface with a rough texture such as wood or concrete that can create a significant amount of spatter (Figure 4.2B). Rough surfaces have protuberances

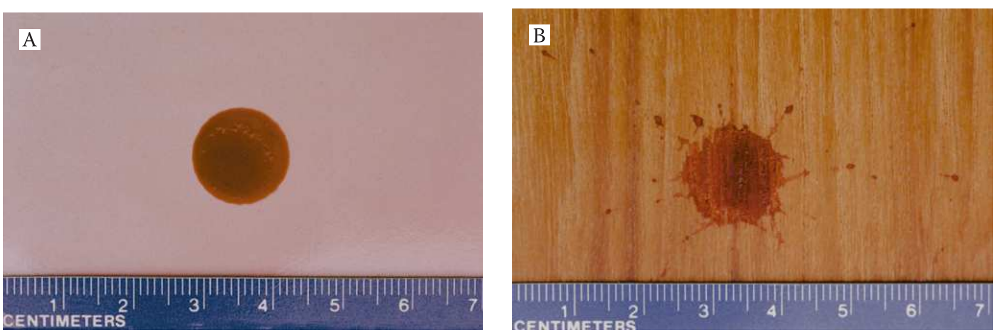


***Figure 4.2*** Effect of target surface texture on bloodstain characteristics and degree of spatter produced from single drops of blood falling vertically 30 inches onto (A) smooth polished tile and (B) wood paneling.

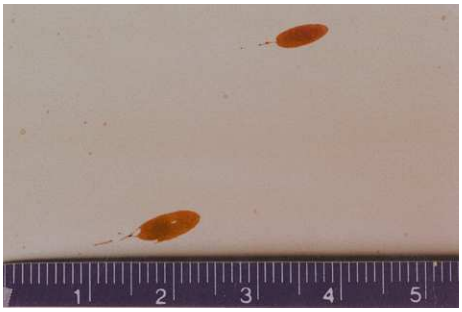


***Figure 4.3*** The direction of travel of these bloodstains is from right to left and downward, as determined by the characteristics of the leading edge of the stains.

***Figure 4.4*** Representation of the point or area of convergence of bloodstains on a wall by drawing straight lines through the long axes of the stains.

that rupture the surface tension of the blood drop and produce spatter and irregularly shaped parent stains with spiny or serrated edges. The effect of target texture must be understood and may require additional testing.

### *4.4.2 Size, Shape, and Directionality*

The geometry of individual bloodstains will generally allow the analyst to determine their direction of flight prior to impacting an object. This is done by examining the edge characteristics of individual stains (Figure 4.3). The narrow end of an elongated bloodstain usually points in the direction of travel. After the **directionality** of several bloodstains has been determined, an area or point of convergence may be established by simply drawing straight lines through the long axes of the bloodstains (Figure 4.4). The area where these lines converge represents the relative location of the blood source in a two-dimensional perspective on the *x*- and *y*-axes. This **area of convergence** will be an area, not an exact point.

The **area of origin** or the location of the blood source in a three-dimensional perspective can also be determined. By establishing the impact angles of representative bloodstains and projecting their trajectories back to a common axis extended at 90° up from the two-dimensional area of convergence along the *z*-axis, an approximate location of where the blood source was when it was impacted may be established. Diagrammatic representations of convergence and origin utilizing the *x*-, *y*-, and *z*-axes are shown in Figure 4.5.

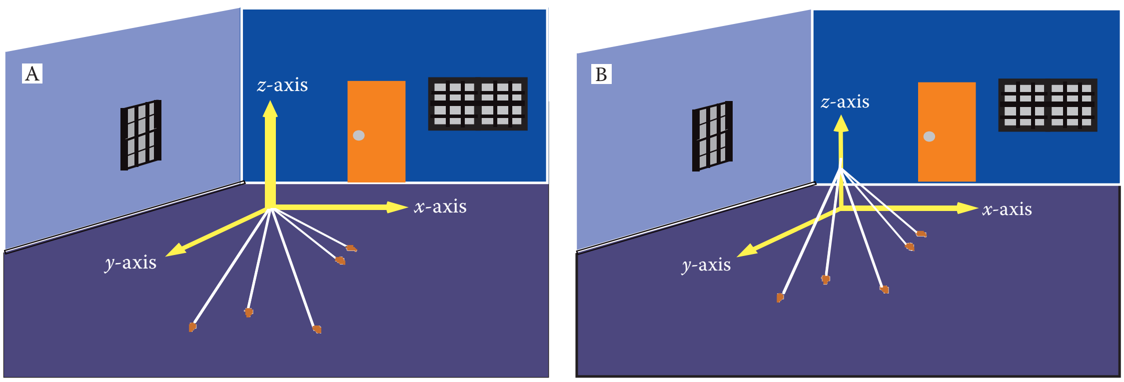


***Figure 4.5*** Graphical representation of (A) the point or area of convergence with the *x*- and *y*-axes and (B) the point or area of origin in space along the *z*-axis of the bloodstains with the use of the angle of impact of the stains.

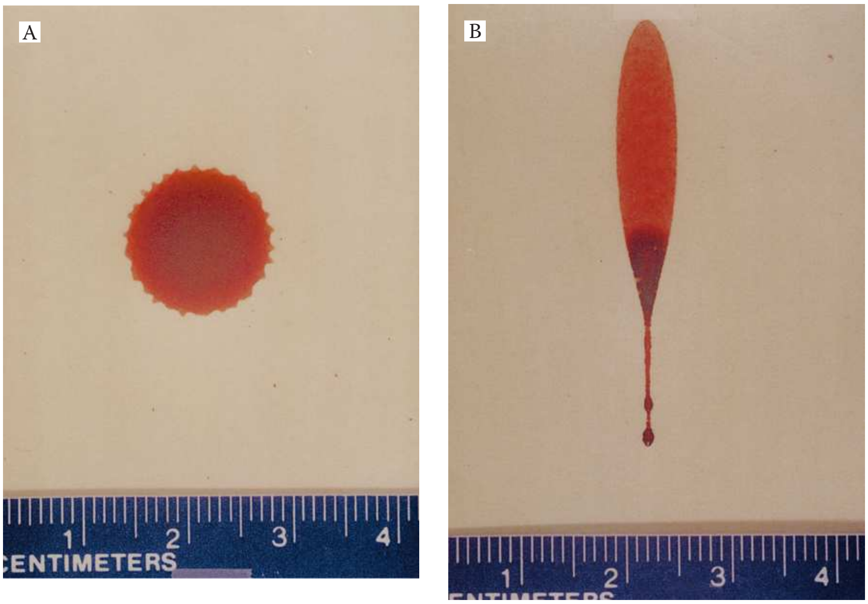


***Figure 4.6*** The shape of a bloodstain resulting from a single drop of blood falling 30 inches onto smooth cardboard at (A) 90° and (B) 10°.

If the **angle of impact** is 90°, the resulting bloodstain generally will be circular in shape (Figure 4.6A). Blood drops that strike a target at an angle less than 90° will create elliptical bloodstains (Figure 4.6B). A mathematical relationship exists between the width and length of an elliptical bloodstain that allows for the calculation of the angle of impact for the original spherical drop of blood. This calculation is accomplished by measuring the width and the length of the bloodstain (Figure 4.7). The width measurement is divided by the length measurement to produce a ratio number less than 1. This ratio is the arcsine of the impact angle, and the impact angle of the bloodstain can be determined by simple calculations. For a circular bloodstain,

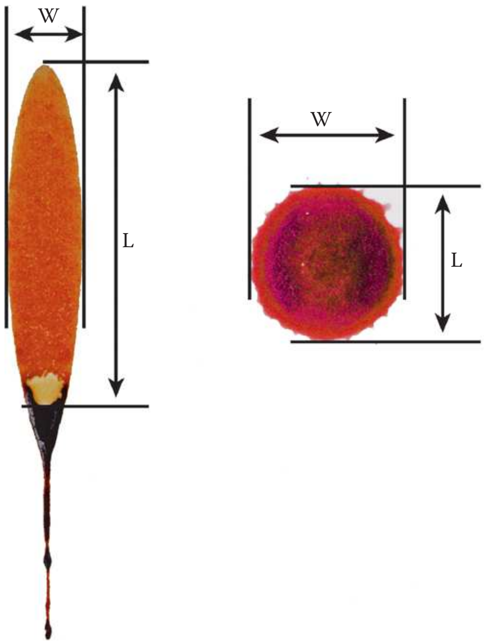


***Figure 4.7*** Measurement of the width and length of bloodstains.

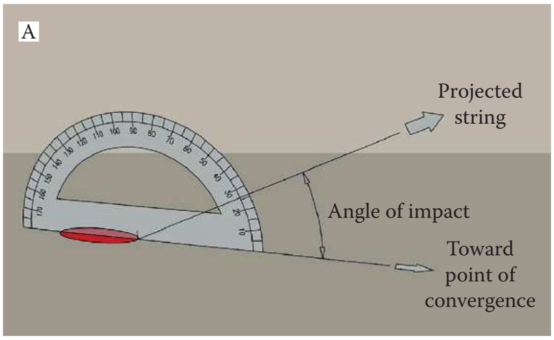



***Figure 4.8*** (A) Method of use of a protractor with the calculated angle of impact to determine the area of origin of a bloodstain. (Courtesy of Alexei Pace, Marsaxlokk, Malta.) (B) Elastic strings placed at the base of selected bloodstains and projected along the $z$-axis to represent the three-dimensional point or area of origin of bloodstains.

the width and length are equal and thus the ratio is 1.0, which corresponds to an impact angle of 90°. For an elliptical bloodstain whose width is one half its length, the width-to-length ratio is 0.5, which corresponds to an impact angle of 30°.

After establishing the angle of impact for each of the bloodstains, the three-dimensional origin of the bloodstain pattern can be determined. One method, known as *stringing*, involves placing elastic strings at the base of each bloodstain and projecting these strings back to the axis that has been extended 90° up or away from the two-dimensional area of convergence. This is accomplished by placing a protractor on each string and then lifting the string until it corresponds with the previously determined impact angle. The string is then secured to the axis placed at the two-dimensional area of convergence. This is repeated for each of the selected bloodstains (Figure 4.8). It is worth noting that the use of strings is being replaced by automated digital methods, but the concepts that underlie both approaches are the same.

The calculated area of origin is always higher than the actual origin of the bloodstains because of the gravitational attraction affecting the spatters while in flight. This gives the analyst the maximum possible height of the blood source. In practical terms, the analyst is attempting to determine how far above or away from a surface the blood source (victim) was located when the spatter-producing event occurred or whether the victim was standing, lying down, or sitting in a chair when the blood was spattered. This method for determining the location of a blood source is not always necessary. For instance, if no blood spatter appears on a table top or chair seat, but spatter associated with a gunshot is found on the underside of the table and chair, then the obvious conclusion is that the victim was on or near the floor when shot. Common sense and quality observations will often resolve the question of where someone was when injuries were inflicted.

### 4.4.3 Spattered Blood

Spattered blood is defined as a random distribution of bloodstains that vary in size that may be produced by a variety of mechanisms. The quantity and size of spatters produced by a single mechanism can vary significantly. The amount of available blood and the amount of force applied to the blood affect the size range of spatters. Spatter is created when sufficient force is available to overcome the surface tension of the blood. The amount of force applied to a source of blood and the size of the resulting spatter vary considerably with gunshot, beating, and stabbing events. The size range of spatter produced by any one mechanism may also vary considerably. Frequently, a single mechanism will create spatters whose size will fit all the categories as outlined in Figure 4.9. Upon examination, the analyst must identify a pattern as a spatter before attempting to ascertain the specific mechanism that created it. A single small stain does not constitute a spatter pattern. Determining the mechanism that created a spatter pattern normally requires more information than merely a look at the pattern; therefore, it is advisable to refer to bloodstain patterns as simply "spatter patterns" until all available information has been reviewed. The identification and analysis of blood spatter patterns are significant for the following reasons:

- Spattered blood may allow for the determination of an area or location of the origin of the blood source when the spatter-producing event occurred.
- If found on a suspect's clothing, spattered blood may place that person at the scene of a violent altercation.
- Spattered blood may allow for determination of the specific mechanism by which the pattern was created.

After identifying small bloodstains as a spatter pattern and gathering pertinent scene, medical, and case-related facts, the analyst may then be able to establish the specific mechanisms by which the pattern was created. The size, quantity, and distribution of these spatters vary depending upon:

- The quantity of blood subjected to impact
- The force of the impact
- The texture of the surface impacted by the blood

In a laboratory environment, the amount of force applied to a blood source and the quantity of blood impacted are easily controlled. However, in actual casework, these factors are not known. In the category of spatter created by an impact mechanism, all three of the mechanisms may produce the similar size ranges of spatter, depending on these factors.

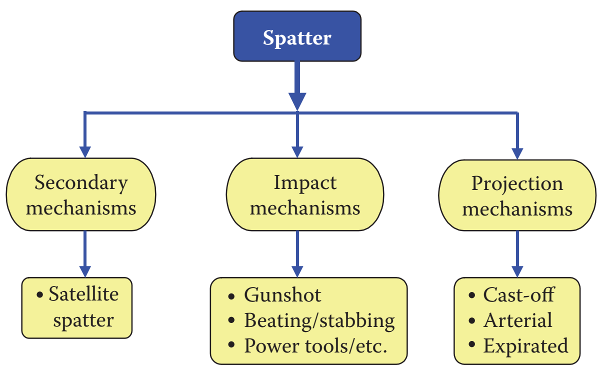


***Figure 4.9*** Categories of blood spatters based on the mechanisms by which they were created.

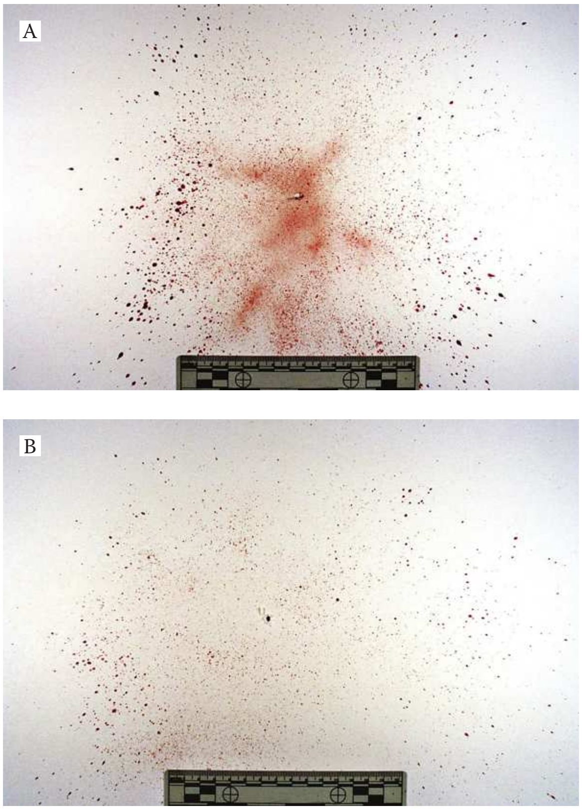


***Figure 4.10*** (A) Forward spatter associated with gunshot. Note the mistlike dispersion of the minute stains sometimes referred to as the "rouging effect." This misting is not often seen in casework. (B) Back spatter associated with gunshot; this is generally seen in less quantity than forward spatter.

### *4.4.4 Impact Spatter Associated with Gunshot*

Impact spatter that is associated with gunshot may produce minute spatters of blood less than 0.1 mm in diameter that are often referred to by analysts as *mist-like dispersions*. This mist-like spatter is not frequently seen, but when observed it is indicative of gunshot. This **misting** effect is not observed in spatter patterns associated with beatings, stabbings, or the production of **satellite spatter** created by blood dripping into blood. Impact spatters associated with gunshot often exhibit a wide size range, from less than 0.1 mm up to several millimeters or more. The size range is dependent on the quantity of available blood, the caliber of the weapon, the location and number of shots, and impeding factors, such as hair, clothing, etc.

Impact spatter of this type is most commonly associated with gunshot, but may also be produced in cases involving explosions, power tools, high-speed machinery injuries, and occasionally high-speed automobile collisions (Figure 4.10). In gunshot cases, two sources can account for impact spatter. When associated with an entrance wound, it is referred to as **back spatter**. This spatter may be found on the weapon and the shooter, especially on the hand and arm areas. Conversely, when the impact spatter is associated with an exit wound, it is referred to as **forward spatter** (Figures 4.10 and 4.11). No forward spatter is produced in cases where the projectile does not exit the body. Generally, the mechanisms that create impact blood spatter will create a variety of sizes of bloodstains that would fit into the categories of impact spatter associated with beating and stabbing events, as well as spatter produced by expiration of blood.

***Figure 4.11*** Horizontal perspective of back spatter and forward spatter produced by gunshot mechanism. The arrow indicates the direction of the projectile. Note the larger quantity and distribution of forward spatter.

### *4.4.5 Impact Spatter Associated with Beating and Stabbing*

Impact spatter associated with beating and stabbing events generally exhibits a size range from 1 to 3 mm in diameter. The spatters may be smaller or larger than this general range, depending on the force of the impact and the quantity of available exposed blood (Figure 4.12). Exposed blood, such as on the skin as a result of a wound, must exist for impact spatters to be created. The blood or bloodied area itself does not have to receive the impact; for example, if a victim has blood on his or her face, a blow struck to back of the head can translate enough force to spatter

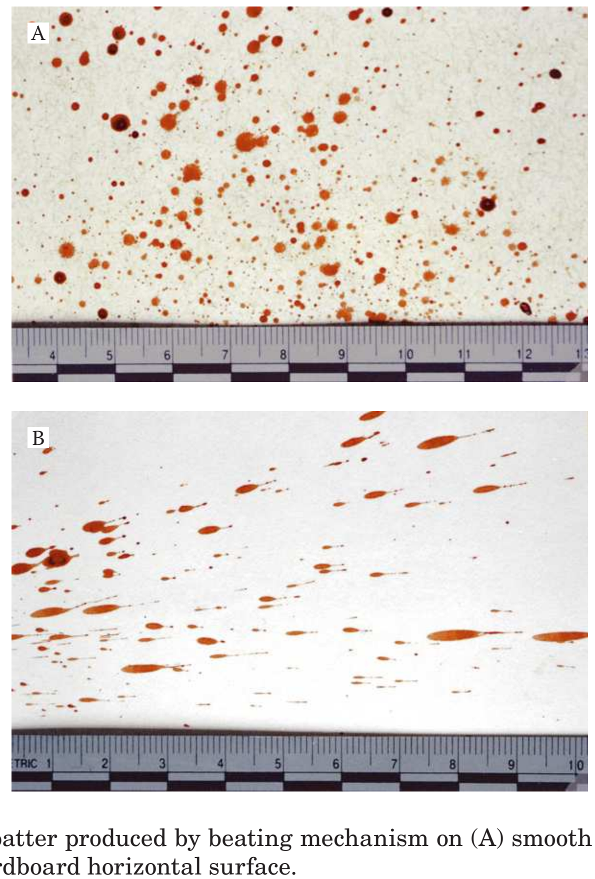


***Figure 4.12*** Impact spatter produced by beating mechanism on (A) smooth cardboard vertical surface and (B) smooth cardboard horizontal surface.

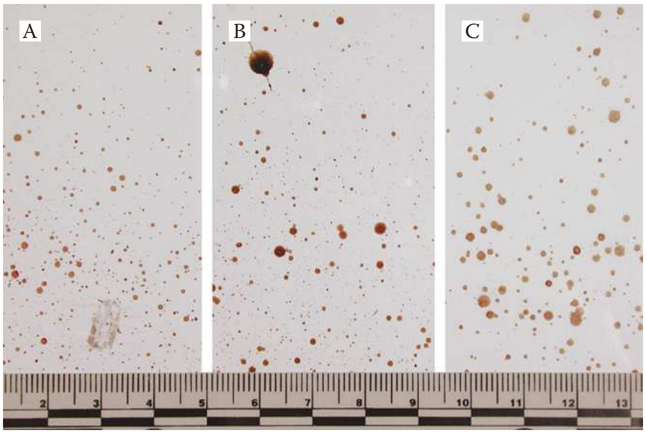


***Figure 4.13*** Comparison of size ranges of spatters produced by (A) gunshot, (B) expirated blood, and (C) beating.

the blood on the front of the head. The weapon used in the assault, whether a sharp object (e.g., knife, glass) or a blunt object (e.g., fist, bat, concrete block) and the number of blows inflicted have effects on the resulting pattern. Mechanisms other than a beating or a stabbing, such as gunshots, expiration of blood, and satellite spattering, may also produce spatter in the size range of less than 1 to 3 mm.

In certain situations, multiple mechanisms may exist, such as any combination of gunshot, beating, stabbing, expirated blood, or satellite spatter resulting from blood dripping onto surfaces. The size ranges of spatters produced by these mechanisms can be similar, so it may not be possible to determine which mechanism produced a specific pattern. Figures 4.12 and 4.13 show how the sizes of these spatters overlap with respect to gunshot, expirated, and beating mechanisms. For this reason, the analyst should consider all possible mechanisms for the production of spatter and utilize all available information. Sometimes, two or more plausible explanations may exist that can explain a spatter pattern, and this must be acknowledged by the analyst. Spatter created by a projection mechanism is produced by the disruption of the surface tension of the blood without an impact (e.g., castoff, arterial, and expirated), as shown in Figure 4.9. These patterns will be discussed in greater detail later in the chapter.

### *4.4.6 Significance of Satellite Spatters Resulting from Dripped Blood*

Single drops of blood will produce small spatters around the parent stain as a result of striking a rough target surface. Spatter produced in this manner is referred to as satellite spatter or satellite stains. When multiple free-falling drops of blood are produced from a stationary source onto a horizontal surface, **drip patterns** will result from blood drops falling into previously deposited wet bloodstains or small pools of blood. These drip patterns will be large and irregular in shape, with small satellite spatters around the periphery of the central parent stain on the horizontal and nearby vertical surfaces (Figure 4.14). Satellite spatters are the result of smaller droplets of blood that have detached from the main blood volume at the moment of impact. These satellite spatters of blood are circular to oval in shape and usually have diameters ranging from 0.1 to 2.0 mm in size or slightly larger.

Several factors influence the appearance of satellite spatter, including the blood drop volume, freshness of blood, surface texture, and distance of the vertical target from the **impact site**. Rough surfaces, such as concrete, produce substantial satellite blood spatter from a single drop impact as well as from blood dripping into blood.

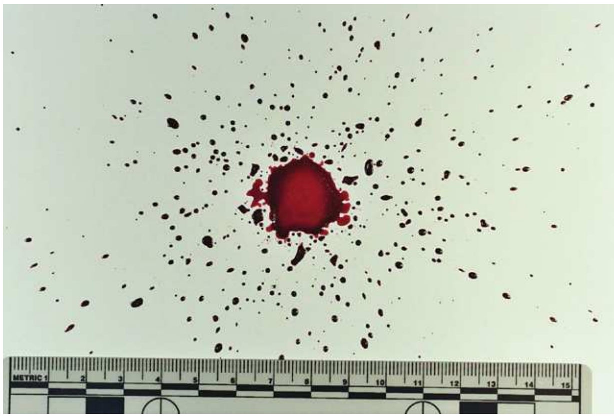

***Figure 4.14*** Drip pattern (blood dripping into blood) produced by single drops of blood falling 36 inches onto smooth cardboard. Note the extent of the satellite spatter around the parent or central stain.

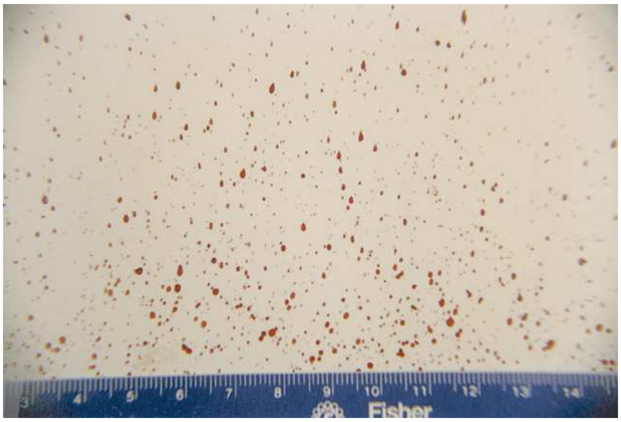


***Figure 4.15*** Satellite blood spatters produced on a vertical cardboard surface within 3 inches of blood dripping into blood on a concrete surface.

The vertical height achievable by the satellite spatter created with a single drop impacting concrete can be as high as 12 inches. Investigators often interpret small spatters of blood on suspects' trouser legs, socks, and shoes as impact blood spatter associated with a beating or shooting due to their small diameters (Figure 4.15). The mechanism of satellite blood spatter causing these stains should be thoroughly explored before reaching a final analysis and conclusion.

From a practical view, it is important that the investigator be able to recognize the types of bloodstains and patterns resulting from free-falling drops based on their size, shape, and distribution and then document their locations. These bloodstains should be categorized relative to the events that produced them, and they should be related to the possible sources and movement of these sources through the recognition of trails and drip patterns.

### *4.4.7 Castoff Bloodstain Patterns*

During a beating with a blunt object, blood does not immediately accumulate at the impact site with the first blow. As a result, no blood is available to be spattered or cast from the first blow. Spatter and **castoff patterns** are created with subsequent blows to the same general area where a wound has occurred and blood has accumulated. Blood will adhere in varying quantities to the object that produces the


***Figure 4.16*** Linear distribution of castoff bloodstains on a vertical surface.

injuries. A centrifugal force is generated as an assailant swings the bloodied object. If the centrifugal force generated by swinging the weapon is great enough to overcome the adhesive force that holds the blood to the object, blood will be flung from the object and form a castoff bloodstain pattern.

The blood that is flung (castoff) will strike objects and surfaces, such as adjacent walls and ceilings in the vicinity, at the same angle from which it is flung or cast. The size, distribution, and quantity of these castoff bloodstains vary. Castoff bloodstain patterns may appear linear in distribution, and the individual stains are frequently larger in size than impact blood spatters (Figure 4.16). Castoff patterns are often seen in conjunction with impact spatters, and a study of each may help determine the relative position of the victim and the assailant at the time the injuries were inflicted. Castoff bloodstains are not always present at scenes where blunt or sharp force injuries have occurred. The arc of the back or side swing may be minimal, especially in the case of a heavy blunt object. Occasionally, analysts will attempt to determine whether the person swinging the object was right- or left-handed. This is dangerous, as many individuals may swing objects effectively with either hand. The analyst must also consider the possibility of back-handed swings that may appear similar. Also, it is not possible to determine with certainty the object that was being swung to create the castoff patterns based solely on the patterns.

### *4.4.8 Bloodstain Patterns Resulting from Large Volumes: Splashed and Projected Blood*

When a quantity of blood in excess of 1.0 mL is subjected to minor force or is allowed to freely fall to a surface, a **splashed bloodstain pattern** will be produced. Splashed bloodstain patterns usually have large central areas with peripheral spatters appearing as elongated bloodstains. Secondary blood splashing or *ricochet* may occur as a result of the deflection from one surface to another of large volumes of blood after impact. When sufficient bleeding has occurred, splash patterns may be produced by the movement of the victim or assailant. These patterns are often created by large volumes of blood falling from a source such as a wound. Larger quantities of splashed blood will create more spatters. A **projected bloodstain pattern** is produced when blood is projected or released as the result of force exceeding that of gravity. When blood of sufficient volume is projected horizontally or downward with force exceeding the force of gravity, the resultant bloodstains exhibit numerous spine-like projections with narrow streaking of the secondary spatters compared

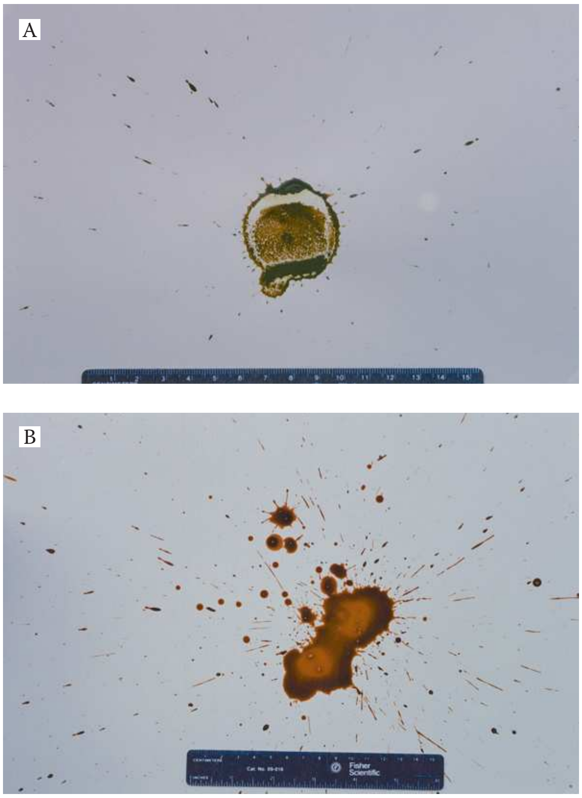


***Figure 4.17*** Bloodstain pattern produced by 1 mL of blood (A) falling downward 36 inches onto smooth cardboard and (B) projected downward 36 inches onto smooth cardboard.

with splashed bloodstains (Figure 4.17). Vomiting blood is an example of projected blood in a large volume. Blood may also be projected from a source or pool by rapid movement or by running through the pool.

### *4.4.9 Expirated Bloodstain Patterns*

As a result of trauma, blood will often accumulate in the lungs, sinuses, and airway passages of the victim. In a living victim, this accumulation of blood will be forcefully expelled from the nose or mouth to free the airways. This type of bloodstain is referred to as an **expirated bloodstain pattern**. The size, shape, and distribution of an expirated bloodstain pattern are often similar to the patterns that are observed with impact spatter associated with beatings and gunshots (Figure 4.18). Because impact spatter due to a gunshot or beating mechanism can closely resemble expirated bloodstain patterns, the deciding factor may be the case history. An expiratory bloodstain pattern cannot possibly be produced unless the victim has blood on their face or in their mouth or nose, or has some type of injury to their chest or neck that involves the airways. Expirated bloodstains may appear diluted if mixed with sufficient saliva or nasal secretions. If the blood has been recently expelled there may be visible air bubbles within the stains due to the blood being mixed with air from the airway passages or lungs. When the bubbles rupture and the bloodstains dry, the areas of previous air bubbles will appear as **vacuoles**. In the absence of these vacuoles within the stains, this type of bloodstain pattern may be misinterpreted. Air bubbles or vacuoles and dilution are not always present in an expirated bloodstain pattern. The presence of air bubbles should be viewed as a presumptive indicator for expirated blood but not conclusive proof.

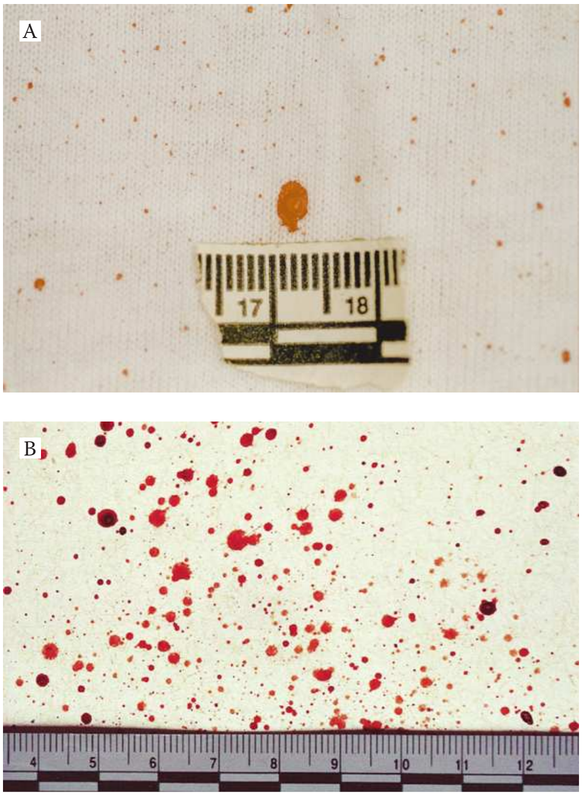


***Figure 4.18*** (A) Bloodstain pattern produced by exhalation of blood from the mouth onto cotton cloth with air bubble in stain pattern. (B) Pattern produced in a similar manner with no evidence of air bubbles or vacuoles. In their absence, the pattern is similar to those produced by beating or shooting mechanisms.

### *4.4.10 Arterial Bloodstain Patterns*

When an artery is breached, blood is projected from it in varying amounts. The size of arterial bloodstains varies from very large gushing or spurting patterns to very small spray types of patterns (Figure 4.19). The type of arterial pattern observed is a function of the severity of the injury to the artery, the size and location of the artery, whether the injury is covered by clothing, and the position of the victim when the injury was inflicted. Obviously, arterial bloodstaining is accompanied by demonstrable arterial damage. The bloodstain pattern analyst should verify his or her hypothesis about an arterial bloodstain pattern by reviewing the autopsy report or speaking directly with the forensic pathologist who conducted the autopsy. These patterns are usually very distinctive due to the overall quantity of bloodstains observed.

### *4.4.11 Transfer Bloodstain Patterns*

When an object wet with blood comes into contact with an object or secondary surface, a blood **transfer pattern** occurs. These patterns may assist an examiner in determining the object that made the pattern (e.g., hair, knife, shoe), because a recognizable mirror image of the original surface or a portion of that surface may be produced (Figure 4.20). When attempting to determine whether an object could have produced a particular transfer pattern, it is usually necessary to conduct a series of experiments using items similar to those in question, as it is never good

***Figure 4.19*** Arterial spurt pattern produced by victim who sustained a severed right carotid artery.

practice to add blood to an evidentiary object. Class or individual characteristics may be determined from distinct blood transfer patterns, such as finger and palm prints or foot and footwear impressions (Figure 4.21). Partial bloody impressions are often chemically enhanced to resolve additional detail.

The differentiation between a minute transfer pattern and an impact spatter pattern on a suspect's clothing may determine whether he or she could have been the perpetrator or merely someone who came into contact with the blood source. If spatter is identified on a garment, that generally means that the wearer of the garment was in the immediate vicinity of the bloodshed event (e.g., beating, shooting). The determination of whether the bloodstains on garments are the results of spatter or transfer is not always easy and often requires experimentation and microscopic examination of the garments.

***Figure 4.20*** Transfer pattern on denim produced by contact with a knife blade containing wet blood.

***Figure 4.21*** Partial fingerprint produced by contact of a finger containing wet blood with smooth cardboard.

## 4.5 Altered Bloodstains

Bloodstains deposited on surfaces at a scene are subject to various forms of change from their original appearance at the time the bloodshedding event occurred. Recognition of these alterations and an understanding of their significance are important for the reconstruction of the event. When blood exits the body, the processes of drying and clotting are initiated. The drying time of blood is a function of its volume, the nature of the target surface texture, and the environmental conditions. Small spatters and light transfers of blood will dry within a few minutes under normal conditions of temperature, humidity, and air currents. Larger volumes of blood may take considerable time to completely dry. Drying is accelerated by increased temperature, low humidity, and increased airflow. Initially, the outer rim or perimeter of the bloodstain will show evidence of drying, which then proceeds toward the central portion of the stained area.

When the center of a dried bloodstain flakes away and leaves a visible outer rim, the result is referred to as a **skeletonized bloodstain** (Figure 4.22A). Another type of skeletonized bloodstain occurs when the central area of a partially dried bloodstain is altered by contact or a wiping motion that leaves the periphery intact (Figure 4.22B). This can be interpreted as movement or activity by the victim or assailant when or after injuries were inflicted.

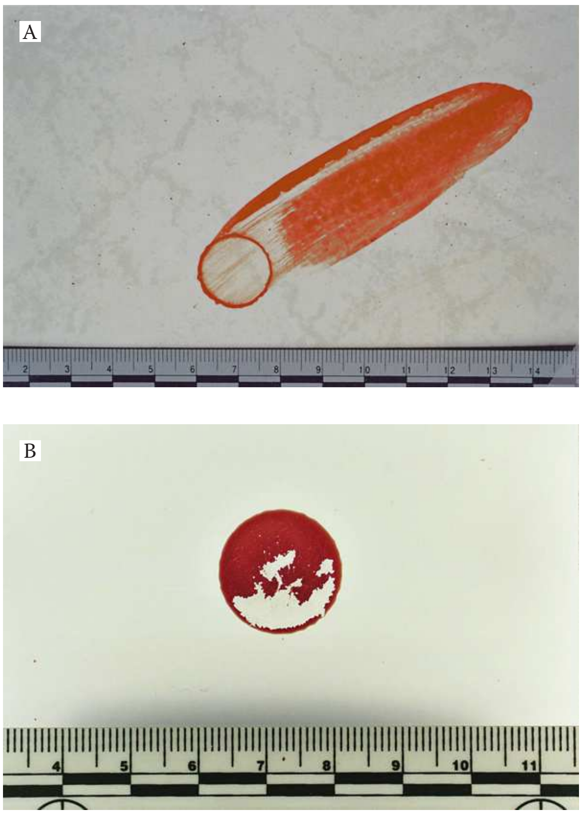


***Figure 4.22*** (A) Skeletonized bloodstain created by drying and flaking away of the central area of the stain. (B) Skeletonized bloodstain produced by a wiping alteration of a partially dried bloodstain, indicating activity shortly after the blood was deposited. Note the remaining peripheral ring of the original bloodstain caused by drying around the edges.

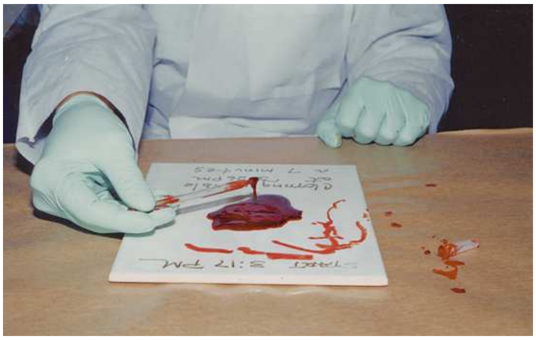

***Figure 4.23*** Demonstration of clot formation in freshly drawn human blood after 7 minutes.

As dried bloodstains age, they tend to progress through a series of color changes from red to reddish brown and eventually to black. The estimation of the age of bloodstains based on color is difficult because environmental conditions and the presence of bacteria and other microorganisms affect the sequence and duration of color changes. Any estimate of time lapse should involve experiments utilizing freshly drawn human blood of similar volume placed onto a similar surface with environmental conditions duplicated as closely as possible.

The clotting process is also initiated when blood exits the body and is exposed to a foreign surface. The appearance and extent of clotted blood at a scene may provide an indication of the amount of time elapsed since the injury occurred. Normal clotting time of blood that has exited the body ranges from 3 to 15 minutes in healthy individuals (Figure 4.23). As a clot progressively forms a jellylike mass, it retracts and forces the serum out of and away from the progressively stabilizing clot. Occasionally a bloodstain analyst will observe clotted impact spatters on clothing or other surfaces (Figure 4.24). Clots of blood may show drag patterns that indicate that additional activity, such as movement or further injury, occurred after a significant interval had elapsed from the initial bloodshed. Evidence of coughing or exhalation of clotted blood by a victim may be associated with post-injury survival time. Existing wet bloodstains at a scene are also subject to alteration in appearance due to smudging, smearing, and wiping activities of the victim or assailant. Changes in the appearance of bloodstains and patterns and additional bloodstains may also be created by paramedical treatment of the victim or removal of the victim from the scene.

***Figure 4.24*** Clotted spatter on fabric exhibiting dark central area with lighter peripheral area of the stain.

***Figure 4.25*** Void area, seen where items have been removed from an area spattered with blood.

Another source of bloodstain alteration is moisture, such as rain or snow, which will dilute existing bloodstains at a scene exposed to the outside environment. Investigators may also encounter indoor scenes and vehicles that have been cleaned with water and detergents or that have been painted after a bloodshed event. Diluted bloodstains may be difficult or impossible to locate without the use of a chemical enhancement process such as luminol treatment. The alteration of bloodstains by heat, fire, or smoke may also cause problems for the analyst. Bloodstains covered with soot may be entirely missed at the scene of a homicide that preceded a fire. Heat and fire may also cause existing bloodstains to fade, darken, or be completely destroyed.

**Void areas** or patterns are absences of bloodstains in otherwise continuous patterns of staining (Figure 4.25). These patterns are commonly seen where items have been removed from an area previously spattered with blood. This permits the analyst to establish sequencing and identify alterations within a crime scene. At a scene containing a considerable amount of spattered blood, the void areas may be utilized to recognize the general location where the spatter-producing event occurred.

## 4.6 Analysis of Bloodstains on Clothing and Footwear

The clothing of a suspect is often a critical piece of evidence that can help link the suspect to the incident through the bloodstain patterns present on his or her garments. Generally, two questions arise with bloodstained garments: (1) Whose blood is on the garment? and (2) How was the blood deposited onto the garment? With advances in DNA technology, the determination of whose blood is on clothing is normally not a problem. The bloodstain pattern analyst determines how the blood was deposited onto the garments. Generally, the deposition of blood onto garments falls into one or both of the following categories:

- *Passive bloodstaining*, including transfer, **flow patterns**, **saturation stains**, and stains resulting from dripping blood
- *Active bloodstaining*, including impact spatter, arterial spurts, expirated bloodstains, castoff, etc.

It is necessary to identify and document the specific patterns prior to attaching any case-related significance to the patterns. Before drawing conclusions from bloodstain patterns on clothing or any other medium, an analyst should request and review any available DNA results.

The analysis of bloodstain patterns on clothing often centers on substantiating or refuting the suspect's version of how his or her clothing became stained with blood. A common example is where a suspect claims to have come into contact with the victim only after the injuries had been inflicted; that is, the suspect was not present when the assault occurred. In such instances, determination of the mechanism of stain creation may have more evidentiary value than identifying the source of the blood. If the bloodstains have transfer patterns in which the blood is deposited on top of the weave of the fabric, then the analyst may substantiate the suspect's claims. If dozens of small spatters of blood are embedded within the fibers of the garment, then the bloodstain evidence refutes the suspect's version of events.

The analysis of bloodstains on clothing can be difficult and often requires experimentation and extensive experience. It has been the authors' experience that bloodstain patterns on textiles are unpredictable due to their varying compositions and textures. For this reason, one should be cautious when interpreting bloodstain patterns on garments. To facilitate the examination of clothing by a bloodstain analyst, the following steps should be taken:

- Establish the manner in which the garments were collected, documented, and preserved prior to their examination.
- Document the garments while the victim or suspect is still wearing them, when possible.
- Allow the bloodstain analyst an opportunity to examine the stains before their removal for DNA analysis. The amount of bloodstaining is usually limited, and the geometry of the stains should be examined before they are consumed in serological analysis. The geometric analysis of bloodstain patterns is a nondestructive examination.
- Take photographs and, if needed, photomicrographs before sample cuttings of stains are removed.
- Obtain a history of where the garment has been and how it has been handled. An example would be a shirt collected from the emergency room floor after a suspect's injuries were treated. The significance of the bloodstain patterns on this shirt could have been compromised, because additional bloodstains may have been deposited on the shirt or existing bloodstains may have been altered.

## 4.7 Documentation of Bloodstain Evidence

Because by definition bloodstains of forensic interest occur at a location that is definable as a crime scene, the same considerations as discussed in the previous chapter apply (for an example, see Case Study 4.1). In addition, when documenting bloodstain patterns, attention should be given to the following points:

- Accurately document the size, shape, and distribution of the individual stains and the overall patterns.
- Include measuring devices within the photographs.
- Use more than one mechanism for documentation (i.e., photographs, notes, diagrams, and video). This overlap should prevent anything of significance from being overlooked.

- If possible, collect articles of evidence that may contain significant or questionable bloodstain patterns.
- Utilize overall, mid-range, and close-up macrophotography when documenting bloodstain patterns. Photographs should overlap so that close-up photographs can be associated with their location within the pattern. Microphotography is also a useful technique to study small spatters. Bloodstain pattern analysis is very visual, and high-quality photographs make it easy to illustrate the significance of bloodstain patterns to a jury.
- Complete the documentation in such a manner as to allow a third party to utilize the photographs, notes, diagrams, and video to place the bloodstain patterns and articles of evidence back in their original locations.

## 4.8 Absence of Evidence Is Not Evidence of Absence

In many cases, the presence of bloodstains originating from the victim and found on the clothing or person of a suspect is powerful evidence to link the suspect to the violent act. It must be pointed out that the absence of blood spatter on a suspect or his clothing does not preclude his or her active participation in a bloodshed event. It is possible to beat, stab, or shoot someone without being spattered with blood, and exceptions to this rule are few. Unfortunately, many defense attorneys attempt to offer the absence of blood spatter on their clients as proof of lack of participation. From a review of the scientific literature and from practical experience, it is not uncommon for an assailant to have little if any blood on his or her person after committing a violent crime. The absence of bloodstaining on an active participant in a bloodshed event has several explanations:

- The directionality of the blows with a blunt object or thrusts with a knife may direct spatters of blood away from the assailant.
- If the site of the injury is covered with clothing or other material during the assault, the amount of spatter may be greatly reduced or absent.
- The assailant may have cleaned up or changed clothing prior to being apprehended.
- The assailant may have worn protective outerwear.
- The assailant may have removed his clothing prior to committing the assault.
- The amount of blood present at a scene described as “covered in blood” or a “bloodbath” may be primarily due to active bleeding from a victim who is still alive or from the draining of blood from wounds of a deceased individual that occurred after the assailant left the scene.
- Individuals have been known to confess to crimes that they, in fact, did not commit.

It is important to recognize that conclusions in bloodstain pattern analysis should not be based on bloodstains or spatter that the analyst would expect to be present, but rather on bloodstains or spatter that are physically present. In most cases, the absence of bloodstains on the clothing of a suspect should neither exonerate nor implicate his or her involvement in a violent act.

## CASE STUDY 4.1: AN INTEGRATED EXAMPLE

Police responded to a single-family residence. Upon arrival, they were met at the front door by the victim's husband, who indicated that his wife had shot herself. Blood was observed on the husband's clothing. The victim was located lying on the bed in the master bedroom. She was clad in pajamas and was partially covered with blankets. The victim had sustained a single gunshot wound to the right side of her head. A Sig Sauer, P226, 9-mm pistol was located on the nightstand adjacent to the bed, the clip had been removed and the slide was locked open. The husband acknowledged removing the clip and clearing the pistol and placing it on the night stand; he also indicated he washed blood off his hands and face in the bathroom, although he denied any involvement in the death of his wife. The victim died as a result of a single close-contact gunshot wound to the right side of her face, just anterior to the right ear. The projectile did not exit her body.

Figure CS4.1.1 depicts the overall location of the body of the victim in the master bedroom bed. A light blue blanket and a white quilted comforter can be seen on the lower half of the bed. Several pillows are located around the victim's head and torso. The east wall of the master bedroom and the entrance to the bedroom are located in the background. A nightstand is located along the east wall between the bed and doorway. A Sig Sauer, P226, 9-mm pistol was located on top of this nightstand. The slide of the pistol was locked open and the clip had been removed from the pistol. The pistol, the clip, and a live round of ammunition were all on the nightstand. Transfer-type bloodstains were located on the majority of the pistol. Bloodstains were present on the exterior of the clip. A dresser with a mirrored top is located on the south wall located to the right of the bed.

Figure CS4.1.2 is a mid-range photograph of the victim's final position after the pillows and blankets were removed. The left arm of the victim was noted to be folded back beneath her torso. A large saturation pattern was located on the fitted sheet adjacent to the victim's left side. This saturation pattern along with the positioning of her right arm is consistent with the victim being on or over this area while bleeding heavily prior to her final position.

Three distinct bloodstain patterns are visible on the east wall, as shown in Figure CS4.1.3. A large saturation pattern is located on the fitted sheet. A number of spatters are present on the fitted sheet to the right of this saturation

***Figure CS4.1.1*** Overall location of the victim in the master bedroom.


***Figure CS4.1.2*** View of the victim's final position after the pillows and blankets were removed.

***Figure CS4.1.3*** Closer view of the spatter distribution on the bed observed in Stain Area D of Figure CS4.1.2.

pattern. Figure CS4.1.3 provides a closer view of the spatter distribution on the bed. The physical appearance, location, and distribution of these spatters are consistent with there being back spatter emanating from the victim's entrance gunshot wound. Figure CS4.1.4 shows the overall appearance of stain patterns on the east bedroom wall. This stain pattern consists of a linear distribution


***Figure CS4.1.4*** View of overall appearance of stain patterns A to C on the east bedroom wall.

***Figure CS4.1.5*** View of stain area A on the east bedroom wall.

of larger spatters, whose direction of travel is right to left and downward. The physical appearance and distribution of these spatters are consistent with their being produced by a projection mechanism secondary to the shooting.

The physical appearance of these bloodstain patterns is consistent with their being transfer bloodstain patterns. These transfer patterns were created, secondary to the shooting, when an object wet with blood came into direct contact with this portion of the wall. The physical appearance and distribution of the individual stains composing the spatter pattern on the right in Figure CS4.1.4 are consistent with there being back spatter associated with the victim's entrance gunshot wound. The direction of travel of the spatters is left to right and upward (Figure CS4.1.5). When a bullet strikes a blood source, the spatter that emanates from the entrance wound is back spatter.

The direction of travel of the spatters is left to right and upward. Representative spatters from this pattern were selected and utilized to establish an area of convergence. Figure CS4.1.6 illustrates the area of convergence of the back spatter pattern on the east wall of the master bedroom. The area of convergence was located at approximately 35 inches from the floor and 64.5 inches from the southeast corner of the bedroom. The black line located below the area

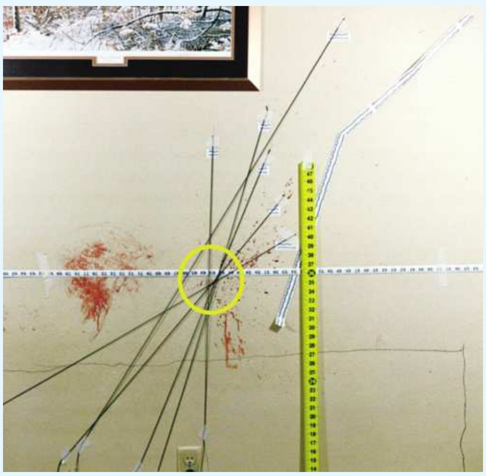

***Figure CS4.1.6*** View of area of convergence of back spatter pattern on the east bedroom wall.

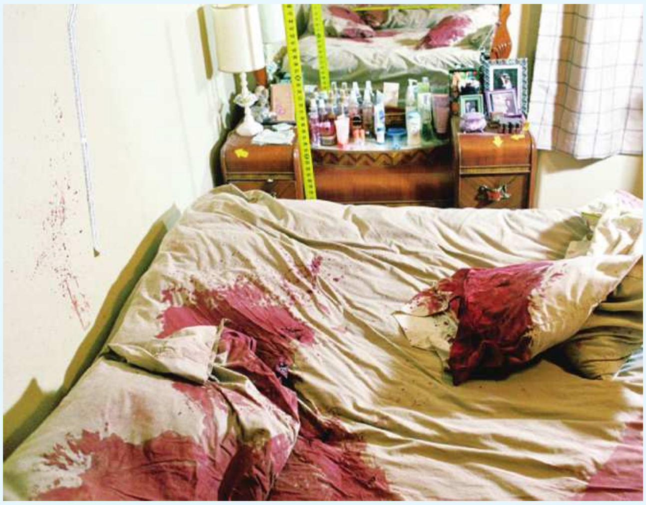

***Figure CS4.1.7*** View of bedroom from the doorway of the master bedroom across the bed.

of convergence in Figure CS4.1.6 depicts the location of the bed along the east wall prior to its removal. The uncompressed mattress height was determined to be between 26 and 28 inches This indicates that the victim's entrance gunshot wound was located approximately 7 to 9 inches above the mattress when her wound was inflicted. This would place the left side of her head close to if not in contact with the mattress and/or pillow when the shot was fired.

Figure CS4.1.7 provides a view of the bedroom from the doorway of the master bedroom across the bed toward the mirror-topped dresser, located along the south bedroom wall. In addition, the overall location of the back spatter patterns located on the fitted sheet and on the east wall can be observed. Spatters were observed on both the right and left side front drawer areas of the dresser. The centermost area of the dresser was void of any blood spatters. The large yellow arrows on the dresser represent the distribution of spatters on the front of the dresser. Samples were collected from both sides of the front of the dresser. The spatters on the protruding drawer front areas of the dresser are consistent with back spatter from the victim's entrance gunshot wound.

Figure CS4.1.8 depicts a series of bloodstains on the bathroom floor. These passive bloodstains are consistent with a blood source moving across the bathroom floor while dripping blood. Some of these bloodstains exhibited a diluted appearance. Figure CS4.1.9 shows the diluted bloodstains located on the bathroom sink counter as well as within the sink basin. A bloodstained tissue/paper product was located on top of the counter. Figure CS4.1.10 shows the diluted bloodstains that were located within the kitchen sink as well as on the kitchen counter adjacent to the kitchen sink. A light blue plastic cup was also located on the counter adjacent to the kitchen sink. This cup also had diluted bloodstains present on its exterior surface.

Photographs taken of the victim's husband on the day of the incident documented spatter on the right side of his face, cheek, and around his right eye. The husband was clad in a gray sleeveless T-shirt. The front of the husband's gray T-shirt can be seen in Figure CS4.1.11. A distribution of small spatters is located over the front of both shoulders and over the top of the right shoulder area. A number of these spatters were encircled on the garment with a black

***Figure CS4.1.8*** View of passive bloodstains on the bathroom floor.

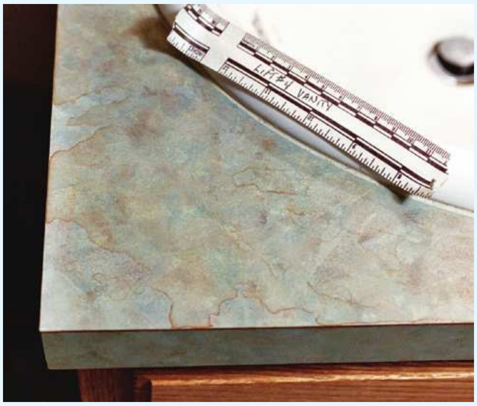

***Figure CS4.1.9*** View of diluted bloodstains located on the bathroom sink counter as well as within the sink basin.

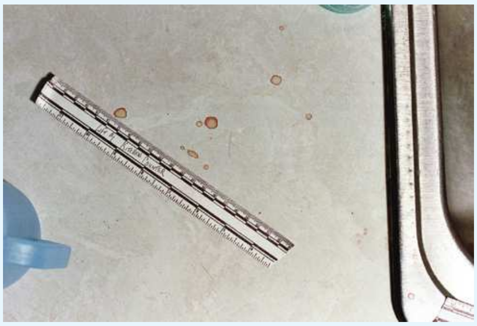

***Figure CS4.1.10*** View of the diluted bloodstains located within the kitchen sink and on the kitchen counter adjacent to the kitchen sink.

marker to illustrate the distribution of the spatters. Two transfer patterns are centrally located on the T-shirt, with the higher and more dense pattern located 19 to 25 inches from the bottom hem. The lower less dense pattern was located 12.5 to 16 inches from the bottom hem. Additional spatters of blood were observed over the mid-section of the T-shirt.

***Figure CS4.1.11*** View of the front of the husband's gray T-shirt.

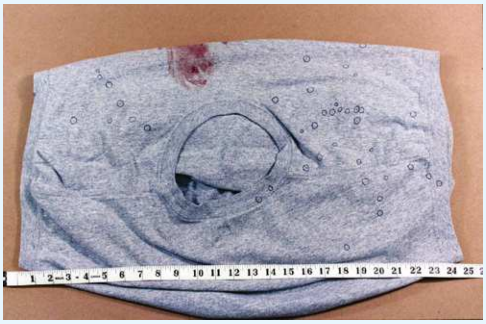

***Figure CS4.1.12*** View of the gray T-shirt from the top down.

***Figure CS4.1.13*** View of spatters located on the upper right shoulder region of the gray T-shirt.

Figure CS4.1.12 provides a view of the T-shirt from the top down that illustrates the distribution of spatters on the upper front of the T-shirt as well as on the back and top of the right shoulder region. Figure CS4.1.13 illustrates the location and physical appearance of the spatters located on the upper right shoulder region of the T-shirt. The physical appearance and distribution of spatters on this T-shirt are consistent with their being the result of back spatter from the victim's entrance gunshot wound. Figure CS4.1.14 provides a closer view of the transfer pattern located on the upper front chest region of the T-shirt in Figure CS4.1.12. Clot-like material is located within this transfer pattern.

## INTERPRETATION OF THE EVIDENCE

The husband gave several versions as to where he was located when the shot occurred, none of which placed him on the south side of the bed in front of the dresser; however, the bloodstain pattern evidence provided enough information to determine what could and could not have happened. The distribution of

***Figure CS4.1.14*** Closer view of the transfer pattern located on the upper front chest region of the gray T-shirt.

spatter on the east bedroom wall, the positioning of the victim's left arm under her body, and the larger saturation pattern on the fitted sheet adjacent to her left shoulder, as well as the distribution of spatter on the fitted sheet adjacent to the large saturation pattern, indicate that the victim's body was rolled or moved over to her final resting position after her gunshot wound had been inflicted.

The bloodstain patterns and forensic evidence of this case are consistent with the victim lying in bed on her stomach with the left side of her face against the bed. The bloodstain evidence in the bathroom and kitchen is consistent with an individual, other than the victim, attempting to clean up a source of the victim's blood from their person and/or objects in their possession. The clot-like material within the transfer pattern on the front of the husband's T-shirt indicates that the victim's blood had begun clotting prior to the T-shirt making contact with her blood. The physical appearance and distribution of the spatters on the upper front shoulder region and back right shoulder region of the husband's T-shirt are consistent with back spatter associated with gunshot. This back spatter associated with gunshot is consistent with spatter emanating from the entrance gunshot wound to the head of the victim.

The physical appearance and distribution of back spatter on the husband's T-shirt indicate that he was in close proximity to the victim's head when her gunshot wound was inflicted. This is further supported by the location and distribution of stains on the right side of the husband's face. The physical evidence is consistent with the husband being on the south side of the bed between the bed and dresser when the victim was shot in the right side of the head. Furthermore, the bloodstain pattern evidence at the scene as well as on the husband's person placed him within the void area of the dresser on the south side of the bed when his wife's injury was inflicted.

The husband ultimately went to trial and was found guilty of murder.

## 4.9 Scientific Working Group on Bloodstain Pattern Analysis: Recommended Terminology

### *4.9.1 Introduction*

The Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) is comprised of bloodstain pattern analysis (BPA) experts from North America, Europe, New Zealand, and Australia. SWGSTAIN serves as a professional forum in which practitioners in BPA and related fields can discuss and evaluate methods, techniques, protocols, quality assurance, education, and research. The ultimate goal of SWGSTAIN is to use these professional exchanges to address substantive and operational issues within the field of BPA and to build consensus-based, or "best practice," guidelines for enhancement of the discipline of BPA. This section provides a recommended list of terms to utilize when teaching, discussing, writing, or testifying on bloodstain pattern analysis. In developing this list, SWGSTAIN reviewed terminology in use across the field of bloodstain pattern analysis.

### *4.9.2 Terminology*

**Accompanying drop:** A small blood drop produced as a byproduct of drop formation.

**Altered bloodstain:** A bloodstain or pattern with characteristics that indicate a physical change has occurred.

**Angle of impact:** The acute angle at which a blood drop strikes a target, relative to the plane of the target.

**Area of convergence:** The area of intersection in two dimensions created by lines drawn through the long axis of individual stains, most often associated with an impact pattern.

**Area of origin:** The area in three dimensions of a blood source most often associated with an impact pattern.

**Back spatter pattern:** A bloodstain pattern resulting from blood drops that travel in the opposite direction of the external force applied. Back spatter is often associated with a gunshot entrance wound.

**Blood clot:** A gelatinous mass formed by a complex mechanism involving red cells, fibrinogen, platelets, and other clotting factors.

**Bloodstain:** A spot or stain made by blood.

**Bloodstain pattern:** A characteristic grouping or distribution of bloodstains which may indicate the manner in which the pattern was deposited.

**Bubble ring:** A ring in a bloodstain that results from an air bubble.

**Castoff pattern:** A bloodstain pattern resulting from blood drops released from a bloodied object in motion.

**Cessation castoff pattern:** A bloodstain pattern resulting from blood drops released from a bloody object as it suddenly stops.

**Directionality:** The path of travel of a blood drop indicated by the stain's shape.

**Directional angle:** The angle between the long axis of a bloodstain and a reference line on the target.

**Drip pattern:** A bloodstain pattern resulting from liquid dripping into liquid, where at least one liquid is blood.

**Drip stain:** A bloodstain resulting from the formation and falling of a drop of blood.

**Drip trail:** A series of bloodstains resulting from blood dripping from a source that is in horizontal motion.

**Edge characteristic:** The physical characteristics at the periphery of a bloodstain that may be described as spines, scalloping, smooth, or irregular margins.

**Expirated pattern:** A bloodstain pattern resulting from blood being forced out of the nose, mouth, or a wound by air pressure.

**Flow pattern:** A bloodstain pattern resulting from the movement of a volume of blood on a surface due to gravity and/or movement of the target.

**Forward spatter pattern:** A bloodstain pattern resulting from blood drops that travel in the same direction as the external force applied. Forward spatter is often associated with an exit gunshot wound.

**Impact pattern:** A bloodstain pattern resulting from an object striking liquid blood.

**Insect stain:** Bloodstains produced as the result of insect activity.

**Mist pattern:** A bloodstain pattern resulting from blood reduced to a spray of localized micro drops as a result of the force applied, often associated with gunshot injuries.

**Parent stain:** The bloodstain from which wave castoff or satellite bloodstains originate.

**Pool:** An accumulation of liquid blood on a surface.

**Projected pattern:** A bloodstain pattern resulting from the ejection of a volume of blood under pressure, often associated with a vascular breach.

**Satellite stain:** Smaller bloodstains that originate during the formation of the parent stain as a result of blood impacting a surface.

**Saturation pattern:** A bloodstain resulting from the accumulation of liquid blood in an absorbent material.

**Serum stain:** The stain resulting from the liquid portion of blood that separates after coagulation.

**Skeletonized stain:** A bloodstain that has been altered after a period of drying, leaving observable peripheral characteristics of the original stain.

**Spatter stains:** Bloodstains resulting from blood drops distributed through the air due to an external force applied to a source of liquid blood.

**Splash pattern:** A bloodstain pattern resulting from a volume of liquid blood that falls or spills onto a surface.

**Swipe pattern:** A bloodstain pattern resulting from the transfer of blood from a bloodied surface onto another surface, with characteristics that indicate relative motion between the two surfaces.

**Target:** A surface onto which blood has been deposited.

**Transfer pattern:** A bloodstain pattern resulting from contact between a wet bloody surface and another surface.

**Void:** The absence of blood in an otherwise continuous bloodstain pattern.

**Wave castoff stain:** A satellite bloodstain that originates from a parent bloodstain due to the wave-like action of the liquid that occurs when the parent drop strikes a surface at an angle.

**Wipe pattern:** A bloodstain pattern resulting from an object moving through a preexisting bloodstain, altering the original stain.

## Chapter Summary

Bloodstain patterns are found at most violent crime scenes. As with any type of crime scene evidence, they must be found, documented, analyzed, and interpreted. Scientific analysis of bloodstain patterns is invaluable for determining what could have happened and what could not have happened to create the observed pattern. Bloodstain pattern analysis has a long history (by forensic science standards), dating back into the 1800s, and it continues to be a critical aspect of crime scene analysis and interpretation. This chapter concludes our study of forensic science as applied to crime scene analysis and processing. In the next section, we will learn about death investigation. Although not all deaths are crimes, many require at least some degree of forensic investigation. As you read through this section, you will see how vital proper crime scene investigation is in cases of homicide or suspicious death.

## 4.10 Review Material

### 4.10.1 Key Terms and Concepts

Angle of impact
Area of convergence
Area of origin
Back spatter
Bloodstain pattern analysis
Castoff patterns
Directionality
Drip patterns
Erythrocytes
Expirated bloodstain patterns
Exsanguination
Flow patterns
Forward spatter
IABPA
Impact site
Leukocytes
Misting
Plasma
Platelets
Projected bloodstain pattern
RBCs
Satellite spatter
Saturation stains
Serum
Skeletonized bloodstain
Specific gravity
Splashed bloodstain pattern
SWGSTAIN
Surface tension
Terminal velocity
Transfer pattern
Vacuoles
Viscosity
Void areas
WBCs

### 4.10.2 Questions

1. What significant physical properties of blood determine the shape of a blood drop in flight?
2. What is the most important factor governing the degree of distortion and amount of spatter created when a blood drop strikes a surface?
3. What factors influence the stain diameter produced by a free-falling drop?
4. How are the physical characteristics of spatter utilized to determine their angle of impact?
5. Compare the size ranges of the spatters in the following scenarios: (1) spatter associated with a beating, (2) spatter associated with a gunshot, and (3) expirated blood.
6. What other mechanisms can create spatters in the same size range as impact spatter encountered in beating, stabbing, and gunshot events?
7. What variables can affect the size, quantity, and distribution of spatters created by an impact mechanism such as beatings and shootings?
8. Discuss the techniques employed for determining the area of convergence and origin of bloodstain pattern.

9. Name two types of bloodstain patterns that require confirmation by autopsy findings.
10. Explain why an assailant might not have any bloodstains on his or her person or clothing after participating in a beating death.
11. Explain the mechanism of castoff bloodstain patterns.
12. What are the features of progressive drying and clotting of blood?
13. How can bloodstains be physically altered at crime scenes?
14. What important information can be derived from the examination of bloodstain patterns?
15. What methods are commonly used to document bloodstain evidence?

## 4.11 References and Further Reading

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# Section II Summary

In this section, we learned about the source of most physical evidence—the crime scene. We learned how scenes are secured, how they are documented, and how they are processed. We focused attention on photography and sketching, which remain key records of any crime scene. We also delved into bloodstain patterns, which are one of the most common types of evidence found at the scenes of violent crimes.

## Integrative Questions

1. Apply the flow chart shown in Figure 3.8 to the case study described in Sidebar 3.3 in Chapter 3.
2. Locate the following article: Sant, S. P., and S. I. Fairgrieve. "Exsanguinated Blood Volume Estimation Using Fractal Analysis of Digital Images." *Journal of Forensic Sciences* 57, no. 3 (May 2012): 610–17. Define exsanguination and discuss its importance in cases where a body is not found but copious quantities of blood is found.
3. Discuss Case Study 4.1 in terms of crime scene documentation as discussed in Chapter 3.
4. Research the current status of the Sam Sheppard case. Why do you think this still fascinates the public nearly 70 years after it happened?

# SECTION III

# Forensic Death Investigation

## Section Overview

In the last section, we talked at length about crime scenes. In forensic science, crime scenes are often associated with one or more homicides. The crime scene investigation in such cases is also a death investigation. This section focuses on forensic death investigation. We begin by discussion forensic pathology and the role forensic pathologists play in death investigation, most famously through performance of an autopsy. Next, we look at death investigation when the death is some time removed from the time when the body is discovered. In these cases, decomposition complicates the investigation, and often the skills of forensic anthropologists are needed to study decomposed and skeletal remains. The section concludes with an exploration of how insects interact with bodies and how the insect evidence can contribute to death investigation. This is forensic entomology, and as we will see all three areas—pathology, anthropology, and entomology—overlap to some extent.

# 5
# Death Investigation

## Chapter Overview

A death that is unexpected or is thought to have been caused by injury or poison is always investigated for the purpose of determining whether it was a homicide—a death caused by an act of another, which was done with intent to produce bodily injury, or death, or done with disregard for the possibility that it could produce injury or death. Accidents can also fall into this category of unexpected death that is worthy of investigation. For example, a death in a car accident is not by itself unexpected, but the question might arise about the driver's condition. Did he have a heart attack that caused the crash? Were there other important factors to be considered? And, finally, suppose a person is beaten during a robbery but recovers, only to die five years later. Was the beating the cause of death? Or was the death unrelated to that event?

Typically, the death investigation system is activated when a **questionable death (equivocal death)** is recorded. For example, if a person with a terminal illness dies in a hospice, typically this would not be a questionable death. If a young and otherwise healthy person dies in a hospital after an appendectomy, that might well be a questioned death. Deaths that are unattended frequently fall into the category of questioned deaths, as do those in which the application of violence is obvious or suspected. Usually a trained death investigator is the first investigative person to respond, much as the crime scene investigator is the first forensic person to examine a scene. The death investigator then makes an initial evaluation of the death and determines if further investigation is warranted. However, the systems of death investigation vary widely across the United States and the world.

# Chapter 5
# Death Investigation*

*Ronald K. Wright*

## Chapter Outline



## 5.1 Systems of Death Investigation

In many ways, the history of forensic science is the history of death investigation. From early in human history, the cause of a death has been important in determining inheritance and taxes as well as determination of any crime or public health issue. For example, death investigation was critical to identifying epidemics of infectious disease and still represents the first line of defense in such cases. Thus, death investigation systems are not exclusively forensic, but rather public service functions.

* This chapter is based on Chapter 2, "The Role of the Forensic Pathologist," and Chapter 4, "Investigation of Traumatic Deaths," both by Ronald K.Wright, as published in the third edition of this text.

In English-speaking countries, the **coroner** is the government agent charged with responsibility for death investigations. These types of investigations were needed not so much for uncovering murder, but for assessing the disposition of the property and wealth of the deceased. The office of coroner has existed in England since before the 10th century, and indeed among their most important duties was tax collection. A wonderful series of articles about the history of the offices of the coroner and sheriff written by Professor Bernard Knight can be found at http://britannia.com/history/coroner1.html. The crowner of the king (the source of the word "coroner") assumed a judicial function as early as the Norman invasion of England. The result was an office unique in modern English law: an inquisitional judge. Generally, English law employs non-inquisitional judges who listen to the evidence brought by parties in litigation. The coroner and most judges who operate under the Roman system of law (Spain, France, Germany, Russia) are inquisitional judges. Their duty is to actually investigate the matters before them. Coroners had many duties in medieval times, including the investigation of the causes of deaths.

English law formed the basis for what became the initial law of the American colonies and subsequently the laws of the states. Death investigation was considered a local, governmental, or county function when the United States was created, and no provision was made in the U.S. Constitution for a coroner. The federal government had no death investigation operations, except in the District of Columbia, until the creation of the Armed Forces Medical Examiner's Office in the Armed Forces Institute of Pathology in the 1990s. Each state enacted coroner's laws, and coroners are most often elected county officials.

### *5.1.1 Medical Examiner System*

A movement beginning in the latter part of the 19th century established standards of education and training for certain professions. Despite the development of standards of professionalism in some areas, a significant problem arose related to the office of the county coroner. Although the coroner was charged with a quasi-judicial function and determined the causes of deaths, no particular education or training was required. Massachusetts was the first state to license nurses, physicians, and lawyers. In 1877, the Massachusetts legislature passed a statute that replaced coroners with **medical examiners** and required medical examiners to be licensed to practice medicine.

As advances in industrialization in both manufacturing and agriculture caused the migration of huge numbers of people from farms to urban areas, big cities in the United States found that many institutions such as the county coroner did not transition well from rural areas. The medical examiner system of death investigation was adopted by cities such as Baltimore, MD; Richmond, VA; and New York City around the time of World War I. Generally, this change was set in motion by local scandals arising from deaths that were improperly investigated by coroners. Several New York City deaths were caused by incompetent administration of anesthesia during surgery. As a result, the law establishing the medical examiner in New York required an investigation into all deaths that occurred during surgery.

At the end of World War II, increasing trade and communication brought about by the automobile, train, and airplane made doing business in multiple jurisdictions increasingly complicated because of the non-uniformity of the laws from state to state and from county to county. The Commission on Uniform State Laws

**SIDEBAR 5.1. CAREER PREPARATION AND EXPECTATIONS**

The education and training required to become a forensic pathologist are extensive and grueling. The first requirement for a forensic pathologist is to graduate from a recognized allopathic (grants a doctor of medicine degree) or osteopathic (grants a doctor of osteopathic medicine degree) medical school. Of course, entry into medical school requires a bachelor's degree or its equivalent. Medical school requires 4 years of study, and the curriculum generally includes very few elective courses. Graduates of medical schools located outside the United States or Canada must pass a test developed by the Education Council for Foreign Medical Graduates (ECFMG).

At least 4 additional years of post-medical school training are required. The training may be in anatomic pathology or a combination of anatomic and clinical pathology. Postgraduate pathology training takes place primarily in hospitals owned by or affiliated with medical schools. Postgraduate training was formerly referred to as internship and residency. The training takes place on the job, and it is the equivalent of an apprenticeship in a trade. An additional year of training is required after completion of postgraduate training in anatomic or anatomic and clinical pathology. The training must be completed at an accredited coroner's or medical examiner's office.

After a candidate has completed 5 years of postgraduate training, he or she must then pass a 2- or 3-day examination to become a board-certified forensic pathologist. It is estimated that 500 forensic pathologists practice in the United States. Because forensic pathology deals with the intersection of law and medicine, an increasing number of forensic pathologists go to law school and obtain law degrees. Additional training is required in fields such as pathology, followed by a residency in forensic pathology. The American Board of Pathology certifies forensic pathologists. There is no set career path for coroners because coroner systems vary across the country. Those interested in death investigation can take training courses and will typically work out of a medical examiner's or coroner' office as the primary responder to death scenes.

was created to develop model laws that could be adopted by every state and thus allow more efficient commerce. One such model uniform statute was the Medical Examiner's Act, which was passed by many states that already had coroners performing death investigations.

In recent years, more laws have established medical examiners, and this development has eliminated or weakened the position of the coroner. However, rural areas are still generally served by elected coroners who are not required to have particular training or experience in medicine, let alone in forensic pathology. Some states have retained their coroners but require training and continuing education. Interestingly, a few states have both coroners and medical examiners, and this often causes confusion. In general, however, the coroner system has become antiquated and is no longer considered the best structure for systematic scientific death investigation. More information on career preparation and history of the discipline is provided in Sidebars 5.1 and 5.2.

The federal government was not involved in death investigation when the U.S. Constitution was written. The creation of the District of Columbia led to establishment of the first federal governmental coroner. The district abolished the coroner's office in favor of a medical examiner's office in 1970. No other federal death

**SIDEBAR 5.2. HISTORICAL NOTE: DR. CHARLES NORRIS (1868–1935)**

Dr. Charles Norris was the first appointed medical examiner for the city of New York and a pioneer of forensic pathology. In addition to his medical skills, Norris was a New York native and grasped the problems faced by the enormous city. His tenure spanned a horrific explosion on Wall Street and the implosion of the stock market in 1927, which resulted in many suicides. Gang warfare was rampant, and Prohibition caused many problems for law enforcement as well as medical detectives. He is remembered particularly for his organizational and managerial skills; in effect, he pioneered the structure of medical examiners' offices in the United States.

investigation program existed until the Armed Forces Medical Examiner's Office was created in 1990. It serves the military and is administered from the U.S. Armed Forces Institute of Pathology.

### *5.1.2 Forensic Pathology and Forensic Pathologists*

A central player in modern death investigation is the **forensic pathologist**. Forensic pathologists are physicians specializing in pathology (the diagnosis of disease) and who then subspecialize in the borderline area between law and medicine that emphasizes the determination of the cause of death. Forensic pathologists are primarily employed by counties to investigate the deaths of persons who die suddenly and unexpectedly or as a result of injury. Civil and criminal litigation often arises from the work done by forensic pathologists. A few forensic pathologists work primarily as consultants in litigation.

Pathologists began to appear in hospitals in Europe and the United States in the middle of the 19th century after advances in the use of microscopes to examine tissues from patients led to the employment of physicians who used these new methods. These doctors came to be called pathologists from the Greek *pathos*, meaning "suffering" or "disease," and *logos*, meaning "word" or "writing." Thus, a pathologist studies disease, its causes, and its diagnosis. Early pathologists examined tumors removed from patients to determine whether the tumors were cancerous. They also examined the bodies of deceased persons to determine the causes of death.

Pathologists later began to manage the laboratories where blood and urine were tested to determine the kinds and amounts of cells and the concentrations of chemicals they contained. By the middle of the 20th century, most pathologists were specialized. Anatomic pathologists performed autopsies and examined tissues under microscopes. Clinical pathologists managed laboratories where body fluids were tested. Most of these physicians worked in hospitals.

The police and the coroners recognized that pathologists were needed to perform autopsies and determine the causes of deaths of people who died suddenly and unexpectedly. Thus, pathologists began doing autopsy examinations for the police, coroners, and medical examiners. By the end of World War II, the formal specialty of **forensic pathology** was recognized by the American Board of Pathologists. Today, in most large cities in the United States, the medical examiner is required to be a forensic pathologist. Forensic pathologists also handle autopsies for coroners in rural areas.

## 5.2 Investigation of Death

The purpose of investigating a death is to determine its cause and manner, and a forensic pathologist must be prepared to present physical evidence to support his or her conclusions about the cause and manner of death. Drawing such conclusions depends on information gained from investigations, descriptions of the death scene, case histories, and autopsy results. The goal of death investigation is to determine the cause, manner, mechanism, and, to the extent possible, time of the death.

### 5.2.1 Cause and Mechanism of Death

The **cause of death** is the disease or injury that initiated the lethal chain of events, however brief or prolonged, that led to death. In other words, the cause of death is the underlying cause, even though a number of complications and contributing factors may have been involved. The **mechanism of death** is a biochemical or physiologic abnormality produced by the cause of death that is incompatible with life. A non-pathologist physician will ask a pathologist about the mechanism of death instead of the cause of death.

Consider the example of a middle-aged man who was taken to a hospital after having been shot multiple times during a robbery. He underwent emergency surgery during which the organs affected by bullets were repaired. The man's condition improved somewhat, but he developed pneumonia followed by renal failure, liver failure, and finally heart failure. Autopsy examination revealed that he had preexisting severe lung and heart diseases. The cause of death was multiple gunshot wounds because those injuries set in motion a lethal chain of events. However, the treating physician was interested in the mechanism of death, the multiple-organ failure, and questioned why this patient developed multiple-organ failure when all his injuries were repaired. The treating physician also wanted to know about the preexisting heart and lung diseases, without which the man probably would have survived. The preexisting diseases were not the cause of death because injury takes precedence over disease in determining cause of death. In other words, injury trumps disease.

The classic example of the precedence of injury over natural disease is a fable told in law school about a person with a paper-thin skull who was knocked down in an altercation. The paper-thin skull was a severe disease. The man probably would have survived the altercation and might not have even been injured if he did not have the severe disease. The cause of death was blunt trauma to the head. The paper-thin skull was a contributory factor.

### 5.2.2 Manner of Death

A forensic pathologist also is called upon to determine the **manner of death**. The manner of death is defined as the fashion in which the cause of death came to be. This explanation is not clear without an explanation of the range of possible manners of death. There are hundreds or thousands of possible causes of death, but only four manners of death (or five, if you consider undetermined or unclassified death as a separate category). The four manners of death are *natural, accidental, homicidal*, and *suicidal*. Sometimes the abbreviation **NASH** is used to express the first four. Natural deaths are caused solely by disease, without the intervention of trauma. The other manners of death all involve trauma. Accidental deaths are due to trauma occurring from acts no reasonable person would have felt had a high probability of producing bodily injury or death. Homicidal and suicidal deaths arise from acts a reasonably prudent person would have felt had a high probability of producing bodily injury or death. The difference between suicide and homicide is merely the person who acted. If the deceased took the action, the death is a suicide. If someone other than the deceased took the action, the death is a homicide.

### *5.2.3 Time of Death*

When a person dies, changes in the body occur that can be used to estimate the time of death: **rigor mortis**, **livor mortis**, and **algor mortis**. It is unknown when these changes were first noted, but certainly by the early 18th century there are writings that indicate that these changes were noted and utilized to determine the time of death. Rigor mortis is the stiffening of muscles that occurs following death. This is a chemical reaction that occurs when the glycogen normally found in muscles is used up following death and is not reformed. Glycogen is used to provide energy for the contraction of muscles, and it is depleted slowly after death. Generally, rigor mortis is seen about 4 hours after death. It can occur sooner if the glycogen has been depleted by exercise of muscles just before death. This is called instant rigor mortis and is described in some war deaths. Electric shock can also lead to shorter periods between death and the onset of rigor. Rigor generally disappears during the period from 24 to 36 hours after death as further decomposition of the muscles leads to their loss of ability to remain fixed in rigor.

Livor mortis is discoloration of the body that occurs from the settling of red blood cells after the blood stops circulating. This can be seen within minutes of death when the blood cells have an increased sedimentation rate due to infectious or other disease. Generally, in light-skinned individuals livor mortis or lividity can be seen within an hour or so after death. In some dark-skinned individuals it may not be possible to see lividity. If a person has died and lost most of their blood volume, then lividity may also not be able to be seen. Lividity becomes fixed, meaning that finger pressure will not blanch the lividity, about 12 hours after death. Lividity slowly disappears with decomposition after 36 hours.

Algor mortis is the cooling of the body that occurs after death, assuming the ambient temperature is lower than body temperature. The general rule of thumb for a nearly nude body exposed to 18° to 20°C is 1.5°C of temperature drop per hour for the first 8 hours. The normal body temperature is 37°C. Thus, if a body has been dead for 4 hours the temperature will be 31°C. Unfortunately, many factors can cause body temperature to deviate from 37°C at the time of death; in addition, the environmental conditions (heat, cold, etc.) all play a role in cooling. Thus, the rule of thumb is truly that—a rough estimate and nothing more.

None of the changes after death results in accurate estimation of the time of death but can be of great help in estimating the time of death. Often other tools have to be used, and even then the time of death is almost always an estimate.

## 5.3 Tools of Death Investigation

The forensic pathologist and others involved in a death investigation should have several sources of information available to help determine the cause, manner, and mechanism of a death. Usually the final responsibility for making the call rests with the forensic pathologist. Although the autopsy is the best known tool of death investigation, and one we will discuss in detail shortly, it is by no means the only tool used. Some of the others are summarized below.

### 5.3.1 Reviewing Medical History

Although forensic pathologists deal primarily with determining the causes of death, obtaining past medical history and understanding the issues raised by that history are important parts of the process of death investigation. Indeed, a medical history is generally the starting point of any investigation. When a death is reported to the coroner or medical examiner, the first issue is to determine whether jurisdiction exists to investigate the death. As most reported deaths do not involve apparent injury, the issue in most jurisdictions is whether the death meets a two-pronged test. First, is the death sudden? The general definition of **sudden death** is a death that occurs within a few hours of the onset of symptoms or death without any symptoms. Second, is the death unexpected? That determination requires a perusal of medical records. If the person has been diagnosed with a disease, the most common of which is cardiovascular disease, then death is somewhat expected, even if sudden, and the death does not fall within the jurisdiction of the coroner or medical examiner.

In addition to inquiring about sudden and unexpected deaths, the medical records must be examined for determination of jurisdiction based on delayed effects of injury. For certifying cause of death, forensic pathologists do not recognize a statute of limitations for fatal injuries. If a person who suffers a gunshot wound that renders him unconscious dies a few years later from pneumonia, the coroner or medical examiner has jurisdiction to determine whether the pneumonia was a consequence of the gunshot wound. Careful study of medical records is required to properly determine the causes and manners of death of persons with histories of trauma.

Finally, because of the efficiency of rescue squads in the United States and Europe, most persons who die of injuries have been treated for those injuries even if the decedent showed no signs of life. Treatment includes the insertion of needles, creation of small or large **incised wounds**, and even fracture of bones. Although it is generally possible to discern between injuries produced after death from those produced before death, such distinction can be difficult when vigorous resuscitation takes place. Review of the medical history is extremely important in situations where people have been treated after injuries.

### 5.3.2 Reviewing Witness Statements

Knowing what witnesses recall of the activities of the deceased prior to death or injury is important to a forensic pathologist. First, this information helps determine jurisdiction in cases where injury is not obvious. Also, because forensic pathology deals with recreating the circumstances of death, knowing what witnesses say happened is extremely valuable in developing questions to be answered. Forensic pathology is generally very effective for refuting witness statements. Understanding the contents of witness statements allows a forensic pathologist to know what questions will be asked. Access to such information can potentially create a problem by prejudicing the judgment of the forensic pathologist, but, on the whole, the system works best when a hypothesis in a witness statement can be tested scientifically.

### 5.3.3 Scene Examination

In the best of situations, forensic pathologists would examine the scene of death or the location where the body was found in every case that they investigate. From a practical standpoint, this type of examination is impractical because of the cost. Many coroner and medical examiner offices in urban areas send forensic pathologists to the scenes of deaths that appear to be complicated or unusual. The information that can be gleaned from examining the scene in person is invaluable. The examination of death scene photographs and reviewing the impressions of well-trained and experienced crime scene personnel can compensate for much that is lost by not having a forensic pathologist examine the scene. However, the perspective of a forensic pathologist at a crime scene cannot be duplicated. Questions of post-injury movement, time between injury and death, time of injury, time of death, time of unconsciousness, and questions that address exactly what happened to cause the death are reliably raised and sometimes answered by examination of the scene. An example case that brings together all of the tools of forensic death investigation is described in Case Study 5.1.

## 5.4 Autopsy

The dissection of the human body to determine the cause of death has been practiced since the early middle ages. **Autopsy** means to look at oneself, so that term hardly seems appropriate. A more technically correct term for the dissection is **necropsy**, or looking at the dead. Autopsy is more commonly used in the United States. In the pre-modern period, dissections of bodies were undertaken only as a means of limiting or stopping postmortem decomposition. Dissection was practiced by the early Egyptians.

Dissection of the bodies of deceased persons is forbidden or restricted by some Middle Eastern religions (Judaism and Islam). It also was forbidden by Egyptian polytheism, although it was required when bodies were prepared for mummification. The prohibitions imposed by Judaism, Islam, and Christianity vary. Such prohibitions occasionally make the performance of an autopsy difficult, if not impossible. Under English common law, the body of a deceased was treated as property for the purposes of burial, and burial was both a duty and a right of the surviving next of kin. Because dissection of a body is deemed to be interference with the duty and right of burial, it requires the permission of the surviving next of kin. One exception is the duty of the coroner or medical examiner to determine the cause of death in certain circumstances. Obviously, if the surviving next of kin is suspected of causing the death, he or she cannot be allowed to prevent the dissection.

Objections by the next of kin to the autopsy or to specific aspects of the autopsy are respected as far as possible. One requirement may be to carefully preserve any blood spilled and return it and all removed organs for burial with the body. This is an important issue for those who practice religions that teach that such preservation of the body is required for proper resurrection. Generally, in the United States, postmortem dissection is mandatory if a death is properly within the jurisdiction of the coroner or medical examiner, and the cause of death is not determinable without dissection.

## CASE STUDY 5.1: STRUCK BY LIGHTNING

In the morning following a thunderstorm, a child was found lying between a metal street light pole and a metal bus bench shelter. The child had been reported missing by his mother the day before. Initially, the child was seen to have his leg lying on the exposed conduit that ran from the bus shelter to the pole. Figure CS5.1.1 shows the child's leg on the conduit. The leg appeared to have an electrical burn. Figure CS5.1.2 shows another view of the apparent electrical burn.

The forensic pathologist on call went to the scene and examined the body, noting the presence of rigor mortis (stiffening of the body after death), the presence of an electrical burn on the leg, and multiple skin lesions from ants that attacked the body after death. Subsequent autopsy revealed an electrical burn as noted at the scene, along with burns of the foot (current penetrated the child's rubberized athletic shoe) and the knee. The hole in the shoe and the burned foot are shown in Figures CS5.1.3 and CS5.1.4. No preexisting disease was noted. The forensic pathologist determined that the cause of death was low-voltage electrocution.

Back at the scene, building inspectors and electrical engineers determined that the transformer that converted the voltage of the street lights to 120 volts of alternating current for the bus shelter developed a short circuit through the insulation. Two ground rods that were supposedly 8 feet in length were only 4 feet long and were a few inches closer together than the building code required. Measurement of the exposed bus bench revealed a small amount of current (estimated to be about 40 volts). The source of the voltage was the short through the transformer. The building department had not issued a building permit for the shelter.

On the basis of these findings, the prosecuting attorney brought charges of manslaughter against the company that contracted for construction of the shelter, against the subcontractor who actually built it, and against the electrician who did the wiring. The forensic pathologist representing the defense had a different interpretation. He concluded that the actual cause of death was lightning, not low voltage electrocution. Thousands of volts were required to arc through the rubber of the athletic shoe. The maximum voltage available from the wiring was 480. Further, thousands of volts were required to break down the insulation in the transformer. Both the shoe and the transformer

***Figure CS5.1.1*** Scene photograph showing electrical burn on child's leg as found.

***Figure CS5.1.2*** Scene photograph of electrical burn after child's body was turned.

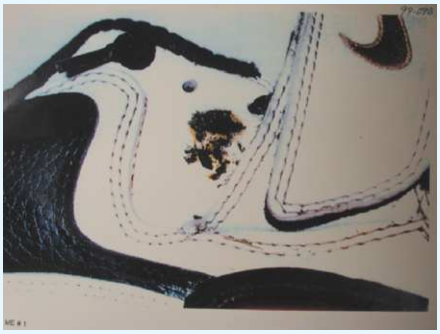

*Figure CS5.1.3* Arc electric burns on tennis shoe of child who sustained electrical burns.


*Figure CS5.1.4* Electrical burns of foot noted during autopsy.

were damaged at the same time by the same lightning bolt. His opinion was that the subsequent burn to the child's leg occurred postmortem as the body lay exposed to the leakage current that energized the conduit.

### 5.4.1 The Autopsy Process

Autopsy examinations generally entail the removal, through incisions, of the internal organs of the chest, abdomen, and head. The customary technique in the United States is the **inframammary incision** beginning at each shoulder, extending to the midline of the body in the lower chest, and extended to the top of the pubic bone. The T-shaped incision has been adopted because it facilitates examination of the tongue and neck. Figure 5.1 shows a T-shaped incision that goes from shoulder to shoulder, then to the midline of the upper chest and down to the pubic bone.

Examination of the brain entails making an incision from behind one ear to behind the other ear, reflection of the scalp by peeling it upward and backward, and then sawing the skull in a circular or tonsorial cut, followed by removing the resulting skull cap. Figure 5.2 shows such a dissection. The brain is sometimes dissected immediately or may be put in a solution of formaldehyde for a week to fix the tissue for better dissection and examination. Fixation is a chemical process that causes proteins to harden; it preserves the tissue and prevents further decomposition.

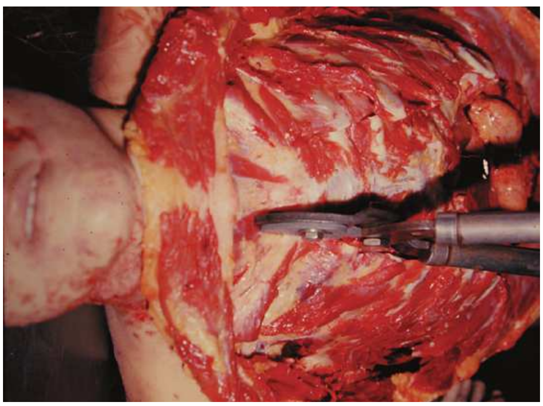

*Figure 5.1* Typical U.S. technique for opening the chest and abdomen during autopsy.

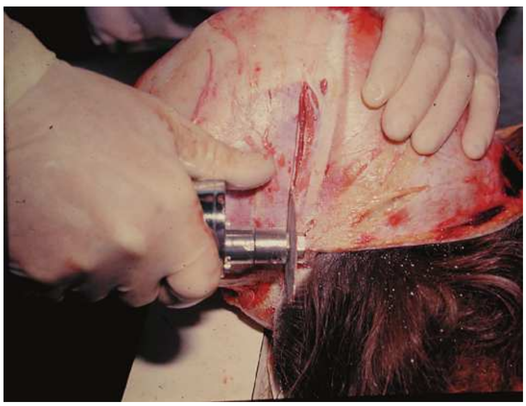

*Figure 5.2* Typical U.S. technique for examining the brain.

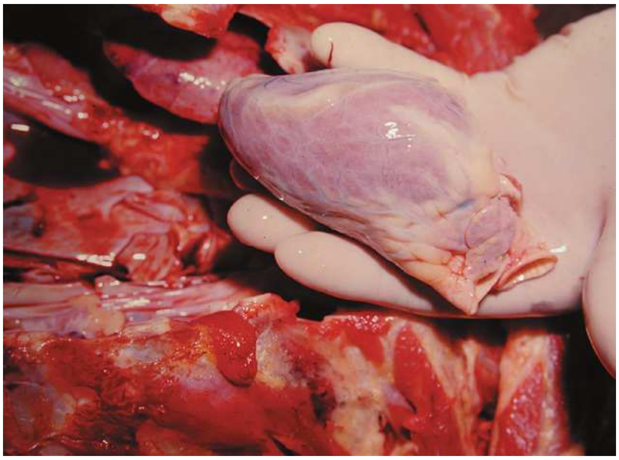

***Figure 5.3*** A normal heart as viewed at time of autopsy.

***Figure 5.4*** Bruised buttocks examined by autopsy incision.

***Figure 5.5*** Normal color of subcutaneous tissue when incised at autopsy (same child shown in Figure 5.4).

After removal, organs are weighed and then dissected to determine disease or injury. Figure 5.3 shows a heart removed from a body in preparation for dissection. Additional dissections may be done but are not generally considered part of a routine autopsy. For example, dissection of the spine and removal of the spinal cord may be required in a case involving possible spinal injury. Occasionally, especially in suspected child abuse cases, a posterior neck dissection is done to reveal any injury to the muscles, ligaments, and spinal cord. Also in children who are suspected of being abused, incisions are made to demonstrate bruises that do not show externally. Figures 5.4 and 5.5 show incisions made in the buttocks of a child suspected to have died from abuse. Figure 5.4 illustrates bruising of the underlying tissue that was invisible without dissection, and Figure 5.5 shows the other buttock that had no evidence of bruising.

Dissection of the legs is generally done if blood clots are found in the lung because clots often originate in the legs. In cases where death occurs in police custody, extensive dissections are required to rule out torture. This includes the examination and dissection of the soles of the feet, arms, and legs to look for evidence of subtle blunt trauma. Information derived from the medical history, witness statements, scene examination, and autopsy guides the performance of additional dissections.

### 5.4.2 Documentation and Specimens

Proper documentation of an autopsy and its findings is as important to death investigation as it is to crime scene investigation. In addition, the pathologist must collect the samples needed by other forensic professionals such as toxicologists and DNA analysts. Toxicological sampling is the most extensive. In most forensic autopsies, specimens are removed for toxicology testing. The usual method of obtaining urine is shown in Figure 5.6. A syringe and needle are used to remove urine for testing.

Blood is usually taken from the aorta and sometimes from large veins. Some drugs redistribute in the postmortem (after death) period and venous blood is considered more reliable than heart or aorta blood for many drugs. Bile is taken from the gall bladder. Blood and urine are routinely used to determine the presence of common drugs of abuse. Alcohol is generally measured in the blood. Opiates, diazepines, and cocaine are measured in the urine. If positive results are found on urine screening, more extensive testing is generally performed on the blood, including quantitation of the drug in question. In addition, information received from the medical history, witness statements, scene examination, and autopsy itself may trigger searches for other drugs and poisons.

Small portions of the internal organs are put into a solution of formaldehyde to fix them and preserve them for further study. Figure 5.7 shows the usual way of preserving tissues. The forensic pathologist selects appropriate sections of diseased or injured and normal tissue. The tissue sections are usually prepared by histology technicians who encase the tissue sections in paraffin. Thinly sliced sections (5 microns thick) of the paraffin blocks containing tissues are mounted on glass slides and stained with inframammary incision dye for examination under a light microscope. Figure 5.8 shows a tray of slides prepared from an autopsy and ready for examination under a microscope.

Most coroners and medical examiners preserve one specimen from an autopsy that can be used for future DNA analysis. Two common methods are used. A spot of blood can be placed on absorbent paper, allowed to dry, and then stored in an envelope. A second common method is to pull head hairs and place them in an envelope. It is important when pulling hairs to remove the bulbs that contain nuclear

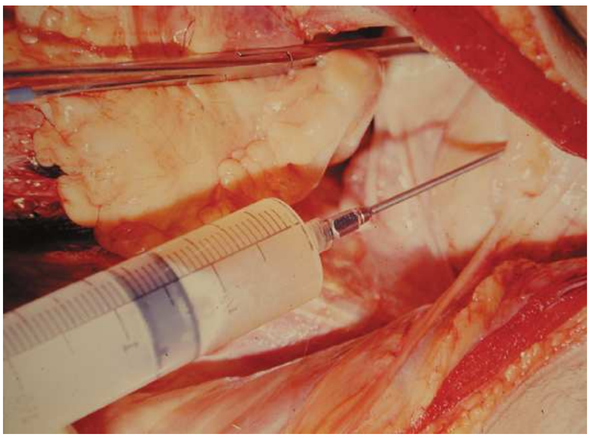

***Figure 5.6*** An 18-gauge needle and 60-cubic centimeter syringe removing urine from bladder during autopsy.

***Figure 5.7*** Formaldehyde solution containing sections of tissue removed at autopsy.

*Figure 5.8* Prepared microscopic slides.

DNA. Cut hair contains mitochondrial DNA. Both techniques, although presenting a slight biohazard, will provide reasonable samples for DNA studies. The potential biohazard arises from the possibility that the person had hepatitis B or C or human immunodeficiency virus (HIV) infection. These diseases can be transmitted by exposure to the virus contained in hair or blood, even if dried.

In older cases and in situations where no DNA sample was preserved, the paraffin-fixed tissue saved after making microscopic slides or the slides themselves generally will provide adequate DNA samples. The only problem is that if the tissue sits for weeks in the formaldehyde solution before embedding in paraffin then the DNA may be hydrolyzed and unsuitable for study. DNA embedded in paraffin blocks or cut into sections and made into slides will not further decompose.

Taking and preserving photographs of the scene and the autopsy are important duties of a forensic pathologist. In larger urban areas, coroners and medical examiners employ professional photographers to perform this function. However, photographs taken by a forensic pathologist are often preferable to those taken by a photographer because the years of training and experience required for a forensic pathologist ensure that relevant and ultimately admissible photographs will be taken.

## 5.5 Investigation of Traumatic Death

Death caused by trauma (injury) can be natural, accidental, suicidal, or homicidal, but whatever the underlying manner traumatic death is frequently the subject of a death investigation. Traumatic deaths may be classified as mechanical, thermal, chemical, or electrical. A mechanistic classification termed *asphyxial death* overlaps the other causes. Asphyxial death is caused by interference with oxygenation of the brain. This asphyxia can occur from mechanical causes (strangulation), chemical causes (cyanide poisoning), and electrical causes (low-voltage electrocution).

**Mechanical trauma** is divided into the categories of **sharp force** and **blunt force trauma**. Blunt force traumas are further subdivided into non-firearm and firearm groups. Firearm trauma can be divided into low velocity and high velocity. Trauma surgeons classify trauma as penetrating or non-penetrating. Penetrating traumas include gunshot and stab wounds. Non-penetrating traumas consist primarily of motor vehicle collisions and falls. The discussion below covers a few of the high points of mechanical traumatic deaths. For further discussion of this topic and other types of traumatic deaths, consult the forensic pathology textbooks listed in the references.

## 5.5.1 Mechanical Trauma

### 5.5.1.1 Sharp Force Injury

Mechanical trauma occurs when an applied physical force exceeds the tensile strength of the tissue to which the force is applied. Sharp force injuries are caused by sharp implements, such as knives, swords, and axes. The amount of force required for a sharpened instrument to exceed the tensile strength of tissue is significantly less than the force required with a blunt object. Of great importance is the fact that blunt objects produce lacerations and sharp objects produce incised wounds. Examining a wound allows one to know whether a sharp or blunt object caused the wound. Unfortunately, many physicians call all relatively discrete injuries lacerations, thereby destroying the distinction between the two types of wounds. Figure 5.9 shows an incised wound, Figure 5.10 shows a laceration, and Figure 5.11 shows representative stab wounds and incised wounds of the neck. A stab wound is produced by a sharp object whose longest dimension is depth as opposed to other surface dimensions. Figure 5.12 shows an incised artery. Note again the sharp edges of the wound that distinguish it from an injury produced by a blunt object.

It is difficult to precisely determine the size of a sharp object from examination of the characteristics of the wound. A stab wound measuring 1-1/2 inch on the surface and 4 inches deep could have been produced by a knife of the same dimensions. However, a 1/2- to 2-inch knife could produce the same wound if thrust in with great force and removed at a different angle from the angle of entry. A larger knife could have produced the wound if it was not completely inserted.

***Figures 5.9*** Incised wound.

***Figures 5.10*** Typical laceration produced by blunt trauma.

***Figures 5.11*** Stab wounds of the chest and incised wound of the neck.


***Figures 5.12*** Incised wound of skin and artery.

Death from blunt and sharp trauma arises from multiple mechanisms, but sharp trauma most commonly causes death by exsanguination or bleeding to death. Thus, a major artery or the heart must be damaged to produce death from sharp trauma.

#### *5.5.1.2 Blunt Force Trauma and Firearms*

Blunt force trauma causes death most commonly when the brain has been significantly damaged; however, blunt force trauma can lacerate the heart or aorta, leading to exsanguination, or it can produce many other complications. Firearms cause a special kind of blunt trauma. Firearm injuries are the most common suicidal and homicidal wounds seen in the United States, which is a reflection of the availability of firearms and the remarkable lethality of these weapons. Of significant importance, from the standpoint of injuries produced, is the velocity of the projectile. The extent of injury produced by a firearm projectile increases as the square of the velocity increases (**kinetic energy**, KE = $1/2mv^2$, where $m$ is mass and $v$ is velocity); we will discuss this in more detail in Chapter 14. The cutoff point between high and low velocity is generally noted as 300 meters per second. Case Study 5.2 discusses a firearms case.

**CASE STUDY 5.2: CIRCUMSTANCES OF A SHOOTING**

Often it is not the cause of death (here, trauma due to firearms injury) that is at issue in a death investigation; rather, it is the manner of death that is in contention. In this case, police were called by a man who said he shot his neighbor. He told the police that his neighbor attacked him with a knife while he was holding his infant child. He said he feared for his own life and that of his child, so he obtained his firearm and shot and killed his neighbor. A store clerk across the street who heard at least part of the altercation confirmed the man's account. The shooter's brother who arrived at the scene just as the altercation ended also confirmed the events. A visit to the scene by the pathologist revealed that, although no blood was present, the bullet hole in the wall still existed. Figures CS5.2.1 and CS5.2.2 show the bullet hole in the hallway some

***Figure CS5.2.1*** Scene photograph of shooting. Defect in wall above and to the left of banister is from a projectile.

***Figure CS5.2.2*** Scene photograph of shooting, taken after the body was removed, showing projectile defect and stairs.

Figure 5.13 is an x-ray of a person who received a high-speed projectile injury to the right upper chest. The dark area is missing tissue. Around the missing tissue are white fragments of lead, often referred to as a **lead snowstorm**, that are diagnostic of a high-speed projectile. High-speed projectiles are only seen in wounds inflicted by high-powered hunting rifles and military rifles. The .44 magnum handgun may achieve the lower ranges of velocity of a high-speed projectile and is the only commonly encountered handgun that is capable of such speed and destruction.

Another classification scheme of gunshot wounds is whether they are penetrating or perforating. A **penetrating gunshot wound** has an entrance wound and no exit wound. A corollary of this is that a projectile must be recovered from the body for every penetrating gunshot wound. A **perforating gunshot wound** has an entrance wound and exit wound. A corollary of this is that generally no projectile will be recovered. Often a key piece of needed information is the distance from the shooter to the victim, and gunshot wounds can assist in that estimation (called **distance determination**). When a firearm discharges, the bullet is ejected from the barrel along with hot expanding gases, unburned propellant, and other residues. How far each component travels is the basis for determining the distance of

months after the shooting. Figure CS5.2.3 shows the body of the decedent as he lay when the police arrived. The shooting was said to have occurred at the landing, but the bullet hole is at the top of the stairs.

As will be discussed in Chapter 14, it is possible to estimate the distance between a firearm and a person shot. The deceased had two gunshot wounds—one distant and the other close. Thus, the weapon was more than 3 feet away for one shot, and it was fired only a few inches away for the second shot. One shot hit the side of the abdomen. It did not strike a major artery and exited the body on the other side. That bullet struck the wall and was the distant shot. The close shot was to the back of the head. It traversed the brain from front to back and slightly upward.

Knowledge of the physiological response to being shot was critical in this case. A gunshot wound of the abdomen that does not hit any major vessels can exert effects for hours or even days or longer. A gunshot wound to the back of the head that traverses the brain will cause instant coma. Thus, the physical evidence in this case refuted the account of the shooter. The shot to the abdomen had to have been the one fired first. The shooter was standing when he fired the shot that produced the hole in the wall. The first shot was fired from more than 3 feet away, not close enough for the shooter to be threatened with a knife. The second shot in effect was a *coup de grace* to the back of the head as the victim fled down the stairs after being shot.

***Figure CS5.2.3*** Scene photograph of the deceased at the foot of the stairs.

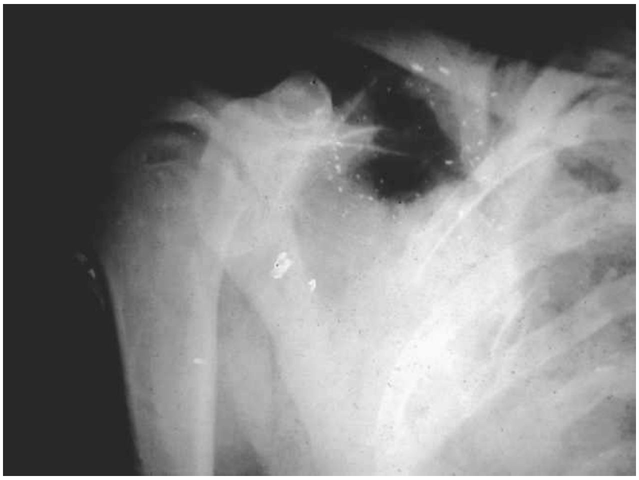

***Figure 5.13*** Massive destruction and lead snowstorm caused by high-speed projectile.

***Figure 5.14*** Contact gunshot wound of the chin. Note smoke, small laceration, and carboxyhemoglobin.

the barrel from the deceased at the time the weapon was discharged. The gases, including the heavy metals, and some smoke from unburned but gaseous carbon, are projected only a few inches. The effects of the gas produce what can be discerned as **contact** or **near-contact wounds**. What can be seen is the blackening of the skin. In addition, the skin will show variable amounts of laceration because the gas blown into the wound tears the skin apart. Finally, the carbon monoxide reacts with the hemoglobin and myoglobin in the wound to produce carboxyhemoglobin and **carboxymyoglobin**. These compounds are bright red, compared to the dull red color of normal hemoglobin and myoglobin. The typical contact gunshot wound seen in Figure 5.14 shows several small lacerations, blackening around the edges of the wound, and red discoloration of hemoglobin in the wound.

Figure 5.15 shows a relatively ordinary contact gunshot wound of the head. Because of the tearing characteristics of the scalp and the reflection of gases by the skull, large lacerations are characteristic of head contact wounds. Indeed, explosion of the head and evacuation of the brain are common effects of gunshots that produce large amounts of gas. As the distance from the barrel to the skin increases, the effect of the gas diminishes and only the unburned powder and bullet are capable of penetrating the skin. Unburned powder that penetrates the skin produces **stippling** or **tattooing** around the defect produced by the bullet. These wounds are referred to as intermediate-range gunshot wounds (Figure 5.16). Most handguns

***Figure 5.15*** Contact gunshot wound of the head. Note large lacerations.

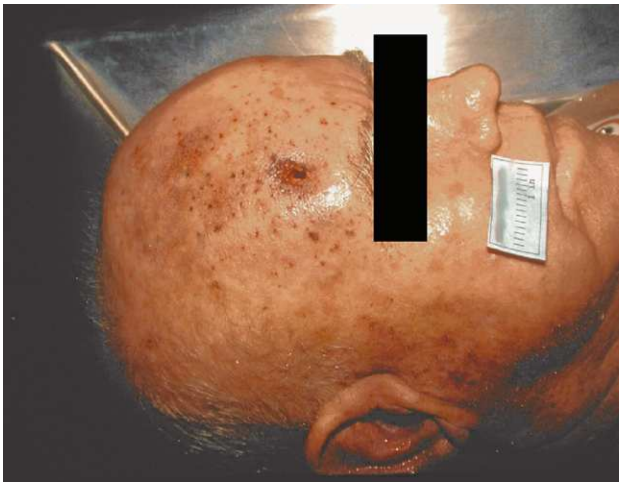

***Figure 5.16*** Intermediate range gunshot wound with 2 to 3 inches of stippling.

produce stippling when the skin-to-muzzle distance is 0.5 centimeter to 1 meter. The pattern enlarges as the distance increases. At 1 meter, the speed of the powder slows sufficiently so that it cannot penetrate the skin. A speed of 100 meters per second is generally considered necessary to produce penetration.

**Distant gunshot wounds** lack smoke and powder effects. Because distant gunshot wounds lack evidence of anything other than the effect of the bullet, the range is indeterminate because clothing and other objects can block the effects of gas and powder. Figure 5.17 shows a typical distant entrance gunshot wound. Distant gunshot wounds lack smoke, soot, and stippling. A typical distant wound has a circular skin defect and a rim of **abraded** (scraped) skin around the edges. The diameter of the skin defect is some indication of the diameter of the bullet, but the estimate is not very reliable because of small differences in diameters of common bullets used by civilians. Bullets vary in size from a nominal 0.22 inches to 0.45 inches. The difference of 0.2 inches is not easily discernible by most observers.

The primary variable in the size of a distant entrance gunshot wound is the elasticity of the skin. The skin of younger people is much more elastic than the skin of older people. The elasticity means skin defects will be smaller. A nominal 0.38 caliber wound in a 20 year old may appear more like a 0.22 or 0.25 caliber wound

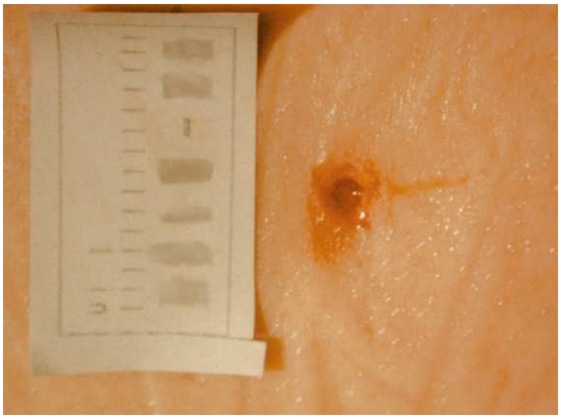

***Figure 5.17*** Typical distant gunshot wound.

in a 50 year old. Obviously, ascertaining the caliber of the weapon from a contact wound is not possible, as the wound bears little relationship to caliber due to the tearing of the skin.

Gunshot exit wounds typically are **lacerated** (i.e., cutting, tearing, or slicing). Although the conventional wisdom is that gunshot wounds of exit are larger than gunshot wounds of entrance, this is not always the case, as can be seen with contact wounds that are much larger than corresponding exit wounds. Indeed, the error rate of emergency room physicians without forensic training in determining directionality of suicidal contact gunshot wounds to the head is almost 100%. These physicians usually rely upon the general rule, but suicidal gunshot wounds to the head are nearly always contact wounds.

Some estimation of the velocity of an exiting bullet can be discerned from the appearance of the exit wound. Exit wounds that are small and slit shaped and have few small side lacerations are due to bullets traveling at slow speeds, and the bullet will generally be found near the body (or even in the clothing). Conversely, exit wounds with many side lacerations are due to a bullet traveling at a very high speed; this is seen best with high-velocity weapons such as military and hunting long arms.

An exit wound will be supported or shored if a gunshot victim wears tight constrictive clothing, such as a heavy leather coat or garments made of tightly woven fabrics, or is against a material such as dry wall that can be penetrated by the exiting bullet and will support the skin. Shored exit wounds look remarkably like entrance wounds. See Figure 5.18 for a fairly representative example of this phenomenon.

***Figure 5.18*** Shored exit wound. Note pattern of clothing that provided the shoring.

***Figure 5.19*** Shored exit wound or entrance with intermediary target.

Often, the rim of abrasion is wider than is typically seen in an entrance wound. This may help in differentiating the two types of wounds. It is important to note that entrance wounds have a unique appearance because they are all supported or shored. An entrance wound is shored by the underlying soft tissue and bone; that is why a rim of abrasion appears around entrance wounds. The skin is compressed for a time before the bullet penetrates the shoring material, then the nose of the bullet abrades the skin. If the skin is not supported, it tears and no abrasion occurs. This is the typical case with exit wounds.

Figure 5.19 shows a shored or supported exit wound that could very easily be an entrance wound with an intermediary target. Supported exits and entrance wounds with intermediary targets are probably not discernible. Of importance is the rectangular shape of the entrance wound. Entrance wounds are generally round when bullets are fired from rifled barrels because the bullet, spinning in an axis 90° off the direction it is traveling, moves through air with its nose pointed in the direction in which it travels. The rotation exerts a gyroscopic action on the bullet that keeps its nose pointed in the direction of travel. The rotation causes a bullet fired from a rifled barrel to be much more accurate than alternative projectiles and is the reason firearms using other types of projectiles are generally antiques that predate the invention of the bullet.

The rotation causes the entrance wound from a bullet to be round or perhaps elliptical if the bullet impacts the skin at an angle other than 90°. If a bullet enters a body sideways, as it appears to have done in Figure 5.19, the bullet was yawing. Bullets do not yaw when fired from a properly designed gun with a rifled barrel. Bullets will yaw if they pass through a medium more viscous than air. Thus, a bullet that ricochets or passes through another person before hitting a second person will yaw. If at the time of entry the bullet is on its side as compared to its direction of flight, it will produce a bullet-shaped entrance wound. Supported exit wounds by definition are caused by bullets that have passed through a person.

The destruction produced by a bullet is proportional to the kinetic energy (KE) loss of the bullet in the body of a person. Increasing the speed and decreasing the diameter of bullets for military weapons have enhanced their effectiveness. During the Civil War, many of the bullets were larger than 0.5 inches in diameter. Most current military ammunitions are near 0.2 inches in diameter. Bullets that exit a body waste kinetic energy. It is difficult to design bullets that will not exit if fired from high-powered, high-velocity long arms. However, with handguns, alteration of the characteristics of the bullet will affect the probability of exiting. Handgun bullets

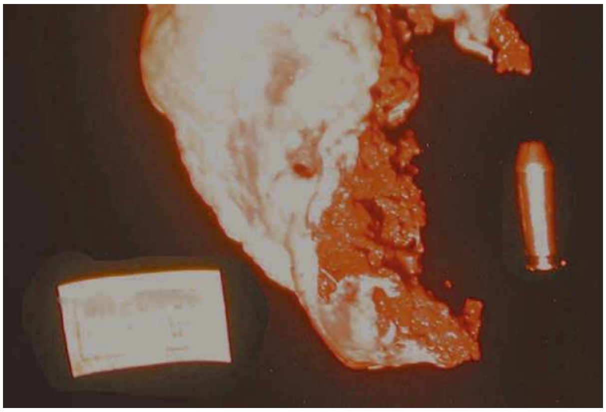

***Figure 5.20*** A heart with most of the left ventricle destroyed by a bullet cartridge case shown at right.

that are designed to enlarge their diameter during passage through tissue are common. They are called **hollow-point bullets** when they are cast with defects in their noses. If jacketed, a common configuration is the half-jacketed hollow point that has a copper or aluminum cast around the lead core and an exposed nose with a hollow point. These bullets expand the most, but the difference in extent of injury is subtle at best. Thus, although bullets that expand should be more effective because they are less likely to exit and will expend maximal kinetic energy, in practice the nose characteristics make little difference in wounding power.

A bullet wound is caused by the creation of a temporary cavity as the bullet passes through a person, the collapse of the cavity, and the shock waves from the cavity's creation and subsequent collapse. When a bullet enters a person, it is traveling much faster than the velocity at which tissues tear, so it pushes tissue out of its way. This stretches tissue beyond its breaking point, but it does not break. It only breaks at a much slower speed than the bullet travels. In the case of high-velocity long arms, where velocities of 1000 meters per second are achieved, the bullet will cross the body entirely before tearing occurs.

The increased velocity can produce entrance wound soot and carbon monoxide effects on the exit wound side if it was a contact wound. Luckily for those determining directionality, these changes are to the inside of the exit wound side. When the tissue finally tears, it retracts back toward its pre-bullet passage location and beyond it due to the velocity the tissue picks up while rebounding. This retraction creates a temporary cavity that again is proportional to the kinetic energy of the bullet. The cavity subsequently collapses after rebounding a few more times. The passage of the shock wave and subsequent collapse of the temporary cavity lacerate the tissues through which the bullet passes and the surrounding tissues. The extent of the damage depends on the organ, but even for relatively slow-speed handgun bullets, the estimate generally is three times the diameter of the bullet. For high-speed long arms, the extent of destruction may be 10 or more times the diameter of the bullet. Figure 5.20 shows a human heart with most of the left ventricle destroyed by a high-speed projectile. The large amount of destruction is typical with high-speed rounds.

Destruction of the heart as seen in Figure 5.20 will cause nearly instantaneous loss of blood pressure and, thus, perfusion of the brain. However, the brain will function for 10 to 15 seconds after it loses perfusion. Any firearm has tremendous stopping power if used to shoot a person in the head.

#### 5.5.1.3 *Other Blunt Force Injury*

Most common blunt force injuries in our society are from transportation collisions, usually motor vehicle collisions. Deaths resulting from such incidents are usually classified as accidents. Rarely are such collisions suicidal or homicidal. Generally, with the exception of gunshot wounds, homicidal blunt trauma in an adult requires a lethal head injury. Injuries to other areas of the body rarely produce death. In children, lethal battery is most commonly due to head injury, but chest and abdominal traumas with laceration of internal organs, such as the spleen, liver, and heart are also seen.

Figure 5.21 shows a female prostitute. Such individuals have extremely high rates of on-the-job injury and death. The Department of Labor does not have reliable statistics on such deaths and injuries because of the illegal nature of the work. The woman was beaten repeatedly about the head with a blunt object that produced the lacerations on her scalp. Bleeding from such injuries is copious because of the vascularity of the scalp. Figure 5.22 shows the weapon that produced the lacerations. Note the considerable spatter visible on the weapon and the blood that flowed from the wound. The most common mechanism of death from blunt head trauma is drowning in the blood that has aspirated into the lungs. Blunt trauma causes fracturing of the bones at the base of the skull that form the roof of the nose and mouth. When these bones are fractured, copious blood exits from the veins at the base of the brain that are lacerated as the result of the fractures. The blood flows into the back of the throat and is inhaled, causing death by the mechanism of drowning.

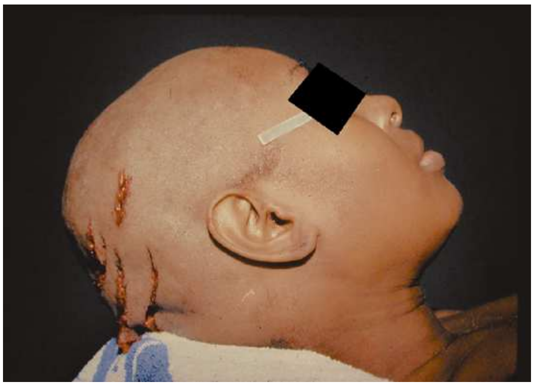

***Figure 5.21*** Typical lacerations of blunt trauma injury.

***Figure 5.22*** Weapon that caused lacerations shown in Figure 5.21.

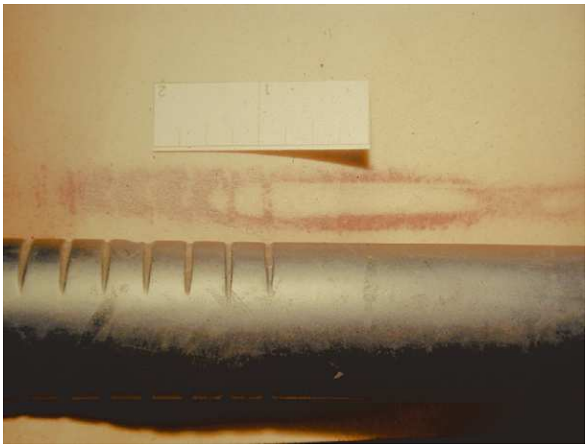

***Figure 5.23*** Patterned contusion of the skin.

Contrary to popular fiction, including movies and television, a single blow or even multiple blows to the head rarely produce loss of consciousness. Even if a blow is of a severity sufficient to fracture the skull and eventually produce death, it will probably not be sufficient to produce instant incapacitation. Persons who are beaten to death by blows to the head typically have defense wounds on the little finger side of the forearm and hand. A person who can see that he is about to be hit will instinctively attempt to ward off the blow by intercepting the trajectory of the weapon, usually with the little finger side of the forearm. If the victim is restrained by physical or chemical means, no defense wounds will occur. The most common chemical restraint is alcohol. Severe intoxication slows reaction time sufficiently to eliminate defense wounds.

Two other terms need to be examined. The first is **contusion**. A contusion is an accumulation of blood in the tissues outside the blood vessels. It is most commonly caused by blunt impact that distorts the tissues sufficiently to break small blood vessels that then leak blood. An important concept is that the pattern of the striking object may be transferred to the person who is struck. Figure 5.23 shows a patterned contusion caused by a striking object. Patterned injuries are important because of the possibility of determining what type of object caused the injury. A second important term is **hematoma**, a blood tumor (*hema*, “blood”; *toma*, “tumor”). Hematomas are contusions with more blood. Characteristically, blunt impact to the head will often produce a hematoma, referred to as a “goose egg.”

### *5.5.2 Chemical Trauma*

Deaths from trauma include deaths that result from the use of drugs and poisons. The most common drug seen in forensic practice rarely kills directly but is a contributory factor in approximately 50% of traumatic deaths. That drug is ethanol (ethyl alcohol), and it is probably the drug with the longest history of abuse by humans, and certainly the most widely abused drug today. Alcohol is generally prohibited by Islamic cultures and some Christian ones, but prohibition is not sufficient to eliminate alcohol as a causative agent in many if not most traumatic deaths.

Alcohol can also kill directly. It is a central nervous system depressant; it slows the reactions and communications from brain and spinal cord neurons. At low levels of intoxication, less than 0.03 gram percent (g%) blood alcohol concentration, the equivalent of perhaps a 330-milliliter bottle of 5% ethyl alcohol-containing beer, most people note a slight improvement in reaction time, probably because of a slowing of inhibitory neurons. At levels of blood alcohol concentration above 0.03 g%, slowing of brain function occurs and reaction time slows. At a level of about 0.25 g%, a person who has not been exposed previously to ethyl alcohol will go into coma if not stimulated; stimulation will cause a regaining of consciousness. At a level around 0.30 g%, the person will be in a deep coma, cannot be roused, and will breathe slowly enough to eventually die. A lack of oxygen causes death resulting from alcohol overdose. Such deaths are infrequent, primarily because a person not exposed to alcohol will start vomiting at a blood level of about 0.10 g%, and further absorption will soon stop. Alcohol overdose deaths are generally seen during chug-a-lug contests in which participants bet on the person who can consume the most distilled spirits. With massive doses of alcohol, the vomiting reflex can be extinguished before it is initiated, resulting in death.

The numbers quoted above are for **naïve consumers** (i.e., not heavy regular) of alcohol. People who consume alcohol and most other drugs of abuse develop a tolerance that causes the effects of the alcohol or drug to diminish at a certain level. As an example, persons with blood alcohol concentrations above 0.30 g% occasionally are seen driving vehicles.

Drugs of abuse other than alcohol produce death generally from the same mechanism. These drugs include barbiturates, diazepams, and opiates. They all produce increasing degrees of coma followed by cessation of breathing and subsequent death. Marijuana is an exception to the general rule concerning drugs of abuse. Marijuana is not known to have ever produced an overdose death. Cocaine is another exception. Cocaine is a central nervous system stimulant. Deaths from cocaine are more unusual than deaths from depressant drugs. At high doses, resulting seizures, extremely high body temperatures, and uncontrolled quivering of the heart are all mechanisms that have been reported to cause death.

While not a drug of abuse, **carbon monoxide** (CO) is a common chemical that produces death. It is an odorless, colorless, explosive gas produced by the incomplete combustion of carbon-containing fuels. Deaths due to CO may be accidental, suicidal, or homicidal. CO is also produced in minute amounts by the body through a reaction that produces **porphyrin**, a component of hemoglobin.

The customary way to measure CO is as the percentage of hemoglobin that combines with it. CO kills by asphyxiation. It cuts off the oxygen to the brain because it binds to hemoglobin 300 times more strongly than oxygen does. Air at sea level contains about 20% oxygen. If one breathes air that is 1/300 of 20%, or 0.06%, the result will be a 50% CO level. Because it is normally produced by the body, about 1 to 2% of hemoglobin is in the form of carboxyhemoglobin, a redder hemoglobin than the **oxyhemoglobin** that combines with oxygen.

Persons who smoke tobacco products as nicotine delivery vehicles commonly have CO levels above 2% and as high as 10%. Blood levels of CO as low as 20% may prove fatal. Levels in persons trapped in enclosed fires often reach 90% before the persons quit breathing and thus expose their blood to CO.

Historically, CO was widely used to commit suicide. One method was to put one's head in an unlit gas stove. During the late 19th and early 20th centuries, the most common source of domestic heating was city gas, a byproduct of the coke produced during the manufacture of steel. With the discovery of natural gas and the popularization of compressed propane, city gas is rarely used. City gas was a very efficient suicide method because it contained up to 5% CO. The second CO source that

## SIDEBAR 5.3. HISTORICAL NOTE: DR. BERNARD SPILSBURY (1877–1947)

The United States had Dr. Charles Norris and England had Dr. Bernard Spilsbury. His career was the subject of several books, including *The Scalpel of Scotland Yard: The Life of Sir Bernard Spilsbury*. His public life was one of fame, his private later life one of tragedy. Two of his sons, also doctors, died during the war period. He died by committing suicide using carbon monoxide. Spilsbury worked many famous cases in his tenure as a forensic pathologist. He became famous based on a 1910 case involving another physician. The accused was a fellow physician named Crippen whose wife had been reported missing in early January. The badly decomposed body was found in July, buried in their cellar. His work was hampered because the killer had removed the head, bones, limbs, and sexual organs from the body. All Spilsbury had to work with was a decomposed torso. Analysis of the tissue revealed the presence of a compound called hyoscine (scopolamine). This drug is a naturally occurring alkaloid that is readily absorbed through the skin, but it is not as toxic as other poisons common in the day. Spilsbury's testimony centered on the difficult task of identification, which he was able to do using a scar found on the abdomen. Crippen was convicted. In 1923, after several more high-profile cases and convictions, he became Sir Bernard Spilsbury. He continued his public service role throughout his lifetime.

became available in the late 19th century was exhaust from internal-combustion engines. Although this method is still employed, it is more difficult because catalytic converters in modern automobiles efficiently reduce the CO concentrations in automobile exhaust, and lethal levels are difficult to attain. (See Sidebar 5.3.)

**Cyanide** is similar to CO in that it interferes with the oxygenation of the brain, acting primarily on the enzymes in the mitochondria of the brain. Cyanide consists of carbon and nitrogen (CN). Like CO, cyanide can be produced by burning, but its effect in producing or contributing to deaths in fires is less important. Cyanide has a distinctive odor. It smells like almonds and can be detected in concentrations as little as 1 part per million, or 0.00001%, by those who can smell cyanide. Unfortunately, as much as 50% of the population cannot smell cyanide. Forensic pathologists should be able to smell cyanide or hire personnel who can smell it. A pathologist who opens the stomach of a person who committed suicide by swallowing potassium cyanide can be killed by the released gas.

Cyanide is generally available as a sodium or potassium salt (NaCN or KCN) and is widely used in industry in electroplating and metal polishing applications. It gained some notoriety as a means of administering the death penalty in California, until it was held to be cruel and unusual punishment and abandoned. The California authorities used potassium cyanide tablets that were dropped into hydrochloric acid to cause release of cyanide gas in the gas chamber. Swallowing cyanide tablets has exactly the same effect in the stomach because the stomach contains hydrochloric acid. Figure 5.24 shows the stomach of a person who died of a cyanide overdose by swallowing potassium cyanide tablets. The intense red color is a hint for the forensic pathologist who cannot smell cyanide, but compounds other than cyanide can also produce a red stomach.

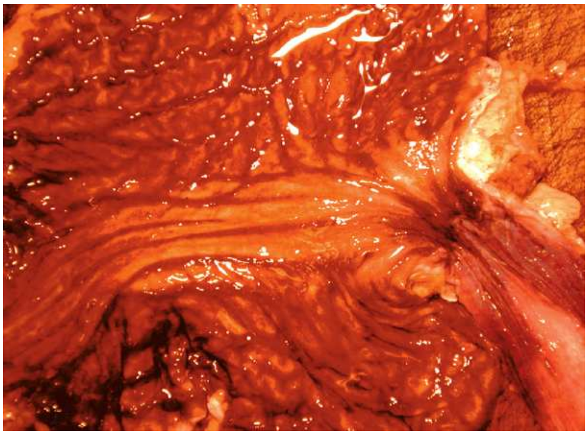

***Figure 5.24*** Stomach with intense gastritis caused by cyanide.

### *5.5.3 Thermal Trauma*

Exposure to excessive heat or cold, **thermal trauma**, may produce death. **Hypothermia** is excessive cold; **hyperthermia** is excessive heat. Both conditions can cause death via a breakdown in the normal mechanisms that maintain body temperature around 37°C (98.6°F). In both, few demonstrable signs can be found at autopsy to diagnose with certainty either condition as the cause of death. Diagnosis requires the absence of other causes of death coupled with a history of exposure to an environment in which either hyperthermia or hypothermia could be expected.

Hypothermia deaths are common in individuals who are intoxicated with alcohol and exposed to cold temperatures. Air temperatures of only 5°C (41°F) have been reported to cause hypothermia deaths. Alcohol intoxication reduces appreciation of the cold while increasing the loss of body heat because of dilatation of the blood vessels on the surface of the body.

Hyperthermia deaths are common in elderly people in northern cities and in infants left in parked automobiles during heat waves. The ability to maintain **homeostasis** (constant body temperature) declines as people age. Dwelling units generally are heated, and hypothermia deaths are often not seen in the elderly population, even though this group is susceptible. However, in the northern states, older dwelling units often lack air conditioning, and heat waves are often associated with large numbers of deaths of the elderly. Small children who are incapable of escaping the interiors of closed automobiles are very susceptible to hyperthermia. The inside temperature of an automobile in the sun can exceed 60°C (140°F) and can be fatal in 10 minutes.

Thermal burns are localized wounds caused by hyperthermia. Generally, temperatures above 65°C (150°F) will produce thermal burns upon direct contact with an object for a few minutes. Deaths from thermal burns occur under a wide range of circumstances, from exposure to hot liquids to burns from flaming hydrocarbons. Deaths from burns are usually delayed and arise from complications after medical treatment. The mechanism of death is generally multiple organ failure.

Persons who die at the scenes of fires most commonly succumb from the inhalation of products of combustion, the most common and deadly of which is CO. They usually die from inhaling the CO that accumulates in enclosed fires before they can die from burns. Most often, when a body is found in a burned structure, the level of

CO can determine whether the person was alive or dead at the time of the fire. It is not uncommon for a person who commits a murder to attempt to camouflage the crime by burning the body of the victim. Finding a body with a 1 or 2% CO level in a burned structure is presumptive evidence that the person was dead, or at least not breathing, after the fire started.

A gasoline fire that traps a person inside a fireball can kill before the person has time to inhale CO. One example is a person who douses himself with gasoline as a means of suicide. Another is a person trapped inside a fireball that results from a gasoline transport trailer fire. In this situation, inhalation stops before the CO level is elevated. The reason for cessation of inhalation is not clear.

### *5.5.4 Electrical Trauma*

The passage of electricity through a person may produce death by a number of different mechanisms. If a circuit of alternating current (AC) at low voltages (below 1000 volts) crosses the heart, the heart will experience **ventricular fibrillation**, a quivering that leads to non-resuscitability within minutes. The heart fibrillates because the AC acts as a pacemaker. AC in the Americas alternates from positive to negative 3600 times per minute (2500 times per minute in Europe). Ventricular fibrillation produces about 300 quivers per minute, which is about as fast as the heart can beat. Low voltage may or may not produce electrical burns, depending on the length of exposure to the circuit. Many seconds of exposure are required to produce electrical burns.

Ventricular fibrillation is less likely with high voltage because the amount of current becomes **defibrillatory** instead of fibrillatory. High-voltage current forces the heart into **tetany**, a sustained contraction that is broken when the circuit is broken. The heart generally will start again with a normal rhythm. However, electrical burn can occur within a fraction of a second with high voltage. In addition to burns, the flow of current through tissues creates holes in the membranes of cells. This is called **poration** and causes the devastating loss of limbs seen in persons exposed to high-voltage circuits.

### *5.5.5 Asphyxias*

We discussed above a few of the causes of chemical and thermal asphyxias; however, a number of other mechanisms that can cause asphyxias fall outside the chemical and thermal categories. Drowning is death by asphyxiation from immersion in water or other liquid. Some deaths from immersion are not asphyxial and result from hypothermia. Exposure of a person to water temperatures below 20°C (68°F) will result in death from hypothermia after exposure of many hours. Exposure to water temperatures near 0°C (32°F) will produce death in a matter of a few minutes.

Drowning victims die as the result of **asphyxia**, the interruption of oxygenation of the brain. A person typically attempts to keep his head above water so he can continue to breathe air. When this becomes difficult, he struggles to maintain the airway, and this increases the need for oxygen. Inhalation of water adds to the excitement. Water that enters the back of the throat is reflexively swallowed. This transmits the negative pressure associated with trying to inhale water to the middle ear via the Eustachian tubes that open during swallowing. The swallowed water enters the stomach. Further efforts to breathe cause water to enter the upper air passages, triggering coughing and additional reflex inhalation.

As the water enters the smaller air passages, the lining muscles go into spasm, thus protecting the alveoli or small air sacs from the entry of anything but air. The spasms create the equivalent of a severe acute asthma attack that traps air in the lungs. Loss of consciousness generally occurs within 1 to 2 minutes of the onset of the struggle, although consciousness may be prolonged if some air can be obtained. Loss of consciousness may be followed by involuntary inhalation attempts and vomiting. Heart cessation occurs a few minutes later. While the heart continues to beat, the pressure that the heart produces in the circulation of the lungs increases greatly, and the right side of the heart dilates from the increased pressure and perhaps from the increase in blood volume from absorbed water from the lungs.

The autopsy findings from drowning will vary depending on whether the drowning event followed the full sequence of events described above. If a person is unconscious when he enters the water, many effects of the excitation phase are not seen because an unconscious person cannot become excited. The excitation results in transmittal of the negative pressure from the upper airway to the middle ears. The negative pressure, along with other asphyxial changes in blood clotting factors, results in hemorrhage into the mastoid air sinuses. In addition, water and materials in the water will be found in sinuses and in the stomach. The lungs will show hyperinflation as a result of the spasm of the muscles protecting the alveoli. The lungs are generally heavier than normal because of the addition of aspirated water and the fluid that accumulates in the lung in all asphyxias.

Small unicellular organisms called **diatoms** are found in most fresh and salt waters in the world. These organisms have silica in their cell walls; thus, they resist degradation by acids. During the late stages of drowning, aspirated water containing diatoms is circulated by the still-beating heart to all the organs. Diatoms are not ordinarily found in bone marrow. Thus, removing bone marrow, digesting it with strong acids, and examining it under the microscope for diatoms can confirm a drowning. Because the types of diatoms present in water vary from place to place and time to time, it is possible to determine the time and place of drowning by identifying diatoms. This technique is especially helpful if a body is severely decomposed and skeletonized.

Asphyxia has many other possible causes including **manual strangulation** (with the hands) and strangulation by **ligature**. Manual strangulation constricts the airway by compressing the neck. Much has been written about the finding of fracture of the **hyoid bone** in manual strangulation. Actually, this is relatively infrequent and seen primarily in elderly women who have osteoporosis, which makes fracturing the hyoid bone easier. Figure 5.25 shows a fractured hyoid bone.

***Figure 5.25*** Fractured hyoid bone with hemorrhage.

***Figure 5.26*** Furrow caused by ligature (hanging).

Note the hemorrhage around the fracture site. This is extremely important to document, as it is very easy to break the hyoid bone while removing it for examination. If a fracture is present and hemorrhage is absent, the fracture occurred after death.

The more common finding in manual strangulation is fracture of the cornu of the thyroid cartilage. The cornu is located in the larynx or voice box and rests against the front of the cervical spine. If the throat is squeezed to close the air passage, the cornu is forced backward against the front of the spine. An even more common finding is hemorrhage into the muscles of the neck, which are collectively called **strap muscles** and are bruised by manual strangulation. Ligature strangulation, whether from hanging or garroting, characteristically does not involve fracture of the hyoid, fracture of the cornu of thyroid cartilage, or hemorrhage into the strap muscles. Generally, the only findings are asphyxia and the presence of a furrow in the neck (Figure 5.26).

## Chapter Summary

The investigation of death is, like crime scene investigation, a team effort that includes many forensic and other professionals. While the forensic pathologist is typically the decision maker, that decision is based on multiple sources of information including medical and case history, scene information, autopsy results, and toxicological testing. The goal of death investigation is to identify the cause, manner, mechanism, and, to the extent possible, time of death. In many cases, particularly when a body is badly decomposed, all of these tasks become more challenging. In the next two chapters, we will see how other forensic professionals come into play in difficult death investigation cases.

## 5.6 Review Material: Key Concepts and Questions

### 5.6.1 Key Terms and Concepts

Abraded
Algor mortis
Asphyxia
Autopsy
Blunt force trauma
Carbon monoxide
Carboxymyoglobin
Cause of death
Contact wounds
Contusion
Coroner
Cyanide
Defibrillatory
Diatoms
Distance determination
Distance gunshot wound
Equivocal death
Forensic pathologist
Forensic pathology
Hematoma
Hollow-point bullets
Homeostasis
Hyoid bone
Hyperthermia
Hypothermia
Incised wounds
Inframammary incision
Kinetic energy
Lacerated
Lead snowstorm
Ligature
Livor mortis
Manner of death
Manual strangulation
Mechanical trauma
Mechanism of death
Medical examiners
Naïve consumers
NASH
Near-contact wounds
Necropsy
Oxyhemoglobin
Penetrating gunshot wound
Perforating gunshot wound
Poration
Porphyrin
Questionable death
Rigor mortis
Sharp force trauma
Stippling
Strap muscles
Sudden death
Tattooing
Tetany
Thermal trauma
Ventricular fibrillation

### 5.6.2 Review Questions

1. The coroner is unique in English law because he is an __________ judge.
2. Forensic pathologists are employed primarily by __________.
3. What other forensic science disciplines are included in forensic pathology training?
4. What is the first determination that must be made when investigating a death?
5. The jurisdiction of the coroner or medical examiner to investigate deaths generally can be categorized as including deaths of what type?
6. Attending the scene of death by the forensic pathologist is most helpful in __________.
7. What is the medical term for stiffening of the body due to postmortem depletion of glycogen?

8. Drug screens are usually performed on what specimen taken during an autopsy?
9. Dissection of the legs is done if what condition is found during the autopsy?
10. Microscopic sections are fixed in a solution of what chemical?
11. Describe four causes of traumatic death.
12. Which causes of traumatic death may be produced by asphyxia?
13. Describe the four manners of death.
14. How are gunshot wounds of entrance classified?
15. Which drug of abuse is most often encountered in the practice of forensic pathology?
16. What three features differentiate lacerations from cuts or incised wounds?
17. Differentiate between a perforating and a penetrating gunshot wound.
18. Describe the unicellular organisms that may prove helpful in diagnosing drowning.
19. Describe the common finding in manual strangulation.
20. Describe the common findings in ligature strangulation.

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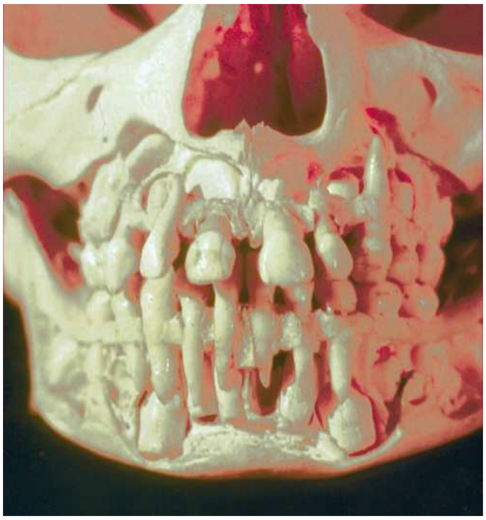
# 6

# Forensic Anthropology



## Chapter Overview

When decomposed or skeletonized remains are found, medical examiners or coroners frequently call on forensic anthropologists to help determine who it might be and what happened to them. This chapter will introduce forensic anthropology as a profession and review the basic procedures an anthropologist goes through when working on a case. The anthropologist often provides the key information about a victim's identification, as well as analysis of trauma and an estimate of how long the victim has been dead.

# Chapter 6
# Forensic Anthropology*

*William D. Haglund and Marcella H. Sorg*

## Chapter Outline



## 6.1 Defining Forensic Anthropology

**Forensic anthropology** can be defined most broadly as the application of the theory and methods of anthropology to forensic problems. However, most forensic anthropologists have been specialists in physical anthropology, the study of human biological function and variation, particularly skeletal biology. (For a discussion of career preparation for this field, see Sidebar 6.1.) Within the last two decades, forensic anthropologists with expertise in archaeological methods have played increasingly important roles in the recovery of human remains.

* This chapter is based on Chapter 8, "Forensic Taphonomy," and Chapter 7, "Forensic Anthropology," both by William D. Haglund and Marcella H. Sorg, as published in the third edition of this text.

## SIDEBAR 6.1. CAREER PREPARATIONS AND EXPECTATIONS

To become a forensic anthropologist, it is necessary to study physical (or biological) anthropology, one of the four subfields of anthropology. Physical anthropologists who get a masters degree or doctoral degree can specialize in forensic anthropology during their graduate work or after they graduate. Joining the American Academy of Forensic Science is one way to begin to build a network that can lead to more experience (see http://aafs.org/choosing-career#Physical%20Anthropology). The American Board of Forensic Anthropology currently certifies practitioners at the doctoral level only. At their website is a list of graduate programs that offer the opportunity to specialize in forensic anthropology (see http://www.theabfa.org/forstudents.html). These programs include a strong emphasis in human anatomy, especially skeletal anatomy, variation in the human species, archaeological techniques, statistical analysis, and taphonomic analysis.

The predominant forensic need for anthropological expertise emerged from the medicolegal context—that is, in the investigation of death and injury for criminal or civil legal purposes. The physical anthropologist's ability to understand the forms and variations of the human skeleton in individuals and populations complements the forensic pathologist's emphasis on soft tissue. Thus, the application of knowledge regarding human skeletal biology has been the foundation of forensic anthropology as a profession. However, this focus has been expanded by some specialists to include: (1) interpretation of primarily outdoor death scenes and postmortem processes (**forensic taphonomy**), (2) recovery of scattered or buried remains (**forensic archaeology**), (3) modeling soft tissue form based on underlying skeletal form (e.g., facial approximation), and (4) biomechanical interpretation of sharp and blunt force injuries, primarily to bone.

Examination of human remains by the forensic anthropologist focuses on three tasks: (1) identifying the victim or at least providing a **biological profile** (age, sex, stature, ancestry, anomalies, pathology, individual features); (2) a **taphonomic assessment**, reconstructing the postmortem period based on the condition of the remains and the recovery context; and (3) providing data regarding the death event, including evidence of trauma occurring at the time of death, the **perimortem** period. An anthropologist who has participated in the recovery will also be responsible for documenting the recovery processes and the forensic taphonomy of the site.

The forensic recovery and examination of human remains involves a multidisciplinary team. Competencies and levels of expertise often cross the disciplinary boundaries of those on the team; for example, both the criminalist and the forensic anthropologist may be trained to excavate buried bodies. Ideally, regular team members function in an interdisciplinary fashion, maximizing shared knowledge and skills and working collaboratively.

In addition to serving as consultants to a medical examiner, coroner, or law enforcement body, forensic anthropologists frequently are asked to testify in court. Although a few forensic anthropologists work full-time in this capacity, most have academic employment at a college or university and do forensic work part-time. They also participate in forensic teams, often international in scope, mobilized to investigate mass fatalities, war crimes, crimes against humanity, and genocide. In the United States, the regional Disaster Mortuary Operational Response Teams (DMORTs) that process mass fatalities for the Federal Emergency Management Agency include forensic anthropologists. In addition, U.S. military death investigations routinely involve forensic anthropologists.

## 6.2 Forensic Anthropology as a Profession

Forensic applications of physical anthropological expertise date back about a century in the United States, roughly as long as the field of **physical anthropology** (sometimes called **biological anthropology**) has been recognized academically. A pivotal article on examining skeletal remains by W.M. Krogman was published in 1939 in the *FBI Bulletin*, marking the commencement of the modern period for the discipline.

During and after World War II and the Korean War, physical anthropologists became involved in the identification of war dead. The need for baseline information on skeletal development and variation in contemporaneous American populations stimulated substantial and systematic data gathering and analysis, mostly on young American males. These very important contributions in human variability research increased forensic anthropology's visibility within physical anthropology and within the forensic community.

In 1972, the Physical Anthropology Section of the American Academy of Forensic Sciences was established. It has expanded from 14 to over 200 members (including many students), and is still growing. In 1977, section members formed the **American Board of Forensic Anthropology** (ABFA) to examine and certify forensic physical anthropologists at the postdoctoral level and to provide oversight in matters of professional conduct. A diplomate of the ABFA must have a doctorate in physical anthropology and a minimum of 3 years of postdoctoral practice in forensic work, in addition to passing a rigorous written and practical examination. There are now about 80 active, board-certified forensic anthropologists, and the D-ABFA (Diplomate of the American Board of Forensic Anthropology) credential is increasingly utilized nationally and internationally to qualify expert witnesses in court.

Physical anthropologists study human physical variation and evolution in relationship to behavioral patterns, including culture. Explanations about patterns of human shape and size (skeletal, dental, and soft tissue **morphology**) include growth and development, pathology, and population differences. These explanations are derived from a theoretical understanding of how population genetics change through time and space—that is, from evolutionary theory.

Because bones and teeth survive over time, many physical anthropologists specialize in human **osteology** and **odontology** as a way of studying past human populations, including the detailed study of skeletal and dental functional anatomy, physiology, pathology, and their variations. This expertise has been of substantial value in forensic cases. It is important to emphasize that, although knowledge of normal skeletal or dental anatomy is critical, the practical and theoretical understanding of human variation is the expertise that allows forensic anthropologists to interpret individual cases.

The adult human skeleton has approximately 206 bones, as shown in Figure 6.1. In children and infants, the number is much higher, because some of the bone **ossification centers** have not yet fused together. Newborn infants can have as many as 405 bones and bone growth centers. Not all adults have the same number

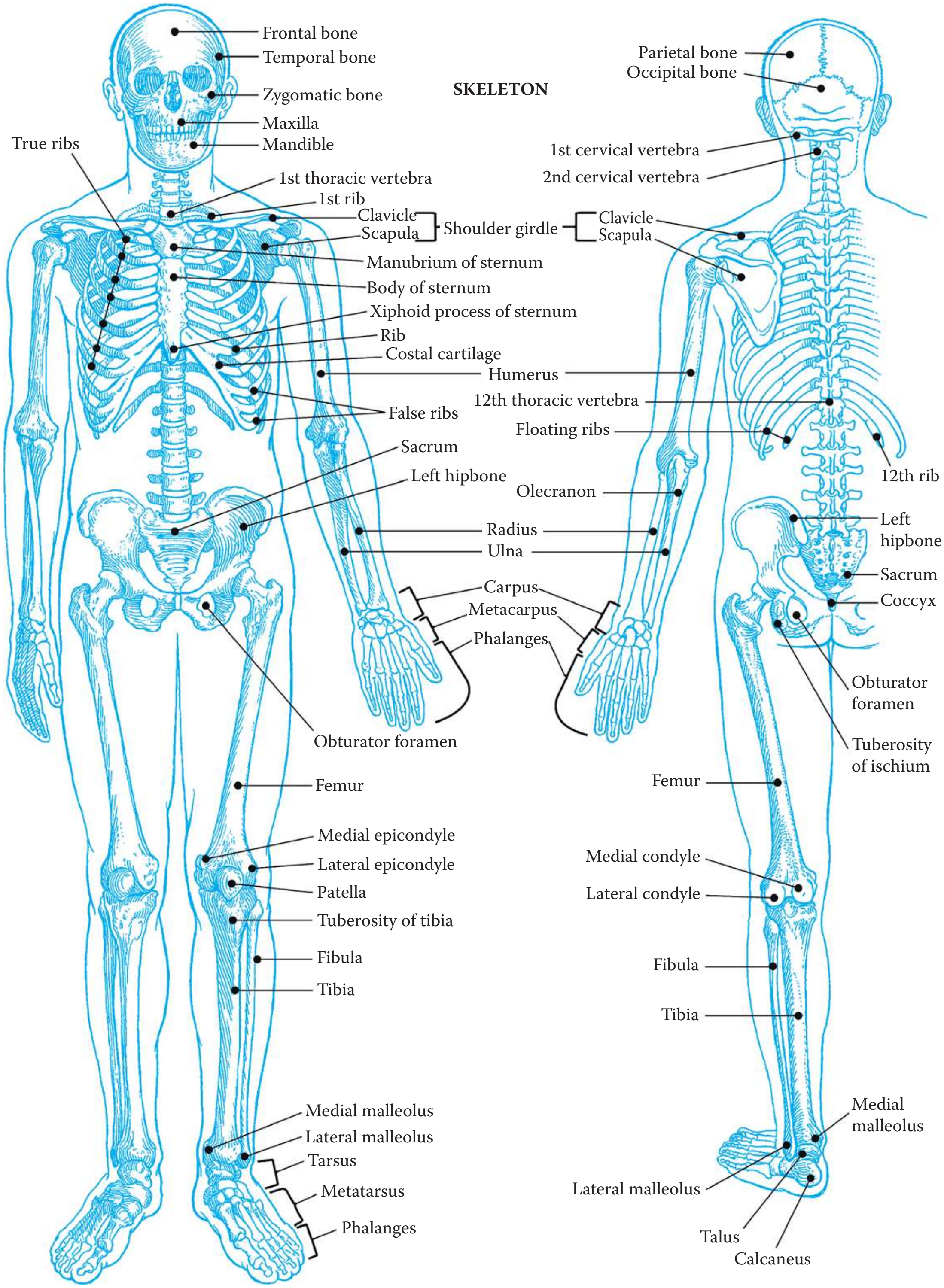



***Figure 6.1*** Adult human skeleton. (From Dox, I.G. et al., *Melloni's Illustrated Medical Dictionary*, 4th ed., CRC Press, Boca Raton, FL, 2001. With permission.)

of bones. There is a minor amount of variation in the number of ribs. While most adults have 12 pairs, some have 11 or 13 on one or both sides; this is unrelated to whether the person is male or female. Some persons have an extra vertebra in their lumbar spine. None of these differences is pathological.

Knowledge about the human physical form and function must then be combined with scientific input regarding **postmortem** changes (taphonomy) in order to interpret the condition of human remains. In an outdoor scene, for example, such changes might include normal **decomposition**, alteration and scattering by **scavengers**, movement and modification by flowing water, freezing, or mummification. Postmortem alterations must be differentiated from the **antemortem** condition of the body in order to estimate time since death, reconstruct the place of death, interpret data regarding cause of death, and sometimes to properly identify the remains.

Forensic anthropologists are frequently called upon to participate in or even direct body recoveries in outdoor settings. Such participation in body recovery is preferred whenever possible because it provides an opportunity to describe and interpret the taphonomic context firsthand. If the forensic anthropologist is not present for the recovery, the examination of the remains should nevertheless include a description and evaluation of the taphonomic condition of the remains, taking into account any contextual or environmental data gathered by the investigators. In some cases, it will be advisable for the forensic anthropologist to return to the scene for further exploration.

## 6.3 Locating Human Remains

The forensic physical anthropologist frequently participates in searches by law enforcement or medical examiner officials, or in recovery of remains in a mass fatality incident or human rights investigation. These searches may be focused on a particular location or a broad area; they may be terrestrial or over water. They may be done in conjunction with search and rescue teams, cadaver dogs trained to find decomposition scent, or divers. In cases where partial remains have already been found, searches by forensic personnel and cadaver dog teams may be conducted to expand the recovery.

The role of the anthropologist ranges from search team member to team leader, depending on the type of case and the jurisdiction. The anthropologist generally does onsite identification of scattered remains as they are found to determine whether they are human and inventories which skeletal elements are present. Onsite evaluation of remains by an anthropologist allows revision of the search strategy in response to emerging anatomical scatter patterns, as well as informing the search team when the remains are complete and the search can be discontinued.

## 6.4 Recovering Remains

Anthropologists frequently work with the medical examiner or with law enforcement to recover human remains. Often remains must be recovered from outdoor scenes. They may lie on the surface, they may be scattered on the surface, or they may be buried. In any of these cases, archaeological techniques are used to improve the recovery success and provide careful documentation of how the remains are positioned. Archaeological techniques are used to map a scatter pattern or to document the relationship between body parts and other evidence at the scene.

Processing a scene involving buried remains, for example, requires considerable effort and expertise, particularly if the remains are decomposed or skeletal. Access to and within the scene needs to be well marked and limited. If the grave has been disturbed by scavengers, it may be reasonable to set two scene perimeters: one for the immediate grave area and another to encompass the potential scatter area that must be searched. The area surrounding the grave or along the access to it should be examined for footprints or other evidence prior to investigatory disturbance. All of the points made in Chapter 3 apply as the recovery area is considered to be a crime scene. The story of one such scene and complicating factors is described in Case Study 6.1.

Initially, a grid will be superimposed on the area to be intensively examined in order to preserve information about the spatial distribution of remains and artifacts within the scene boundaries. The grid may actually be marked off on the ground or provided with a computerized **total station**, a computerized device that digitally records three-dimensional locations of features and artifacts.

The entire area must be photographed and documented before any work begins. The area should be examined for insects that may be associated with the body; these are collected and preserved. Any living plants directly associated with the body and indicative of postmortem interval must be collected as well. It is frequently advisable to use a metal detector, particularly where vegetation or leaf cover is present. If the metal detector signals a "hit," the location should be flagged.

The remains are removed gradually, with the position of the skeletal parts and artifacts being recorded before they are moved. Photographs, and sometimes video recordings are used to document each stage of the removal. This work must be done very carefully, because the crime scene is actually destroyed as the evidence and remains are removed. The process can only be done once, so it must be done correctly.

A screening area is selected in a location that has already been thoroughly searched and is somewhat convenient to the grave. Here, material from the grave and surrounding area will be systematically sifted through a screen to reveal human remains, artifacts, fibers, and associated insects (flies, beetles, larvae).

The next step is to clear a staging area for the excavation, usually consisting of at least several yards in every direction surrounding the grave. Leaf or other vegetation cover is removed and screened, section by section. Bushes and saplings can be cut and removed, unless they are associated with the burial. Sod covering over the grave, if present, can be carefully removed and examined. A second pass with the metal detectors is done to locate the sources of previous hits and new areas of interest. Metal artifacts are documented and removed. Sediment samples are taken from the perimeter area and the grave matrix.

An attempt is frequently made to learn the position of the body prior to excavation. Some graves may need to be excavated from the side to preserve vertical stratigraphic patterns (e.g., a mass grave). Excavation of the grave is done with small instruments such as trowels and brushes, taking care to preserve the original perimeter of the grave and any hairs, fibers, or artifacts associated with the body. If the body is fresh or decomposing, it will be necessary to prevent damage to the deteriorating soft tissue surfaces.

As soon as the hands, feet, and head are exposed and photographed it is a good idea to bag them to prevent loss of small bones, fingernails, teeth, or other evidence. In the case of burned or fragmented remains or remains of infants and children, it may be necessary to remove the body along with the surrounding sediment in order to prevent loss of tiny fragments of bone; the material can then be screened in the morgue or laboratory. In these cases, a finer mesh screen can be used.

## CASE STUDY 6.1: A CLANDESTINE BURIAL DISTURBED BY SCAVENGERS

A young woman in her early 20s was killed in New Hampshire. The body was brought to a wooded area in Maine and buried in a shallow grave in July. Eighteen months later a witness directed investigators to the general search area. The nearly empty grave was located by a cadaver dog. The area surrounding the grave, approximately 1/2-mile in all directions, was searched by State Police and Warden Service personnel using two cadaver dogs followed by a shoulder-to-shoulder search.

All materials located were flagged, mapped using a total station, and recovered; most were found within 50 feet of the grave (see Figures CS6.1.1 through CS6.1.8). The immediate grave was excavated by the forensic anthropologist to expose the original grave contours, which were diagrammed and photographed. The search was then expanded to look for items that might have penetrated the grave floor. Prior to excavating, the leaf cover was removed and examined carefully. The soil from within the grave and several inches of topsoil within ten feet surrounding the grave were sifted through a 1/4-inch screen. Three mandibular incisors were found within the grave, along with a ring. A large amount of long, light brown hair was found within and immediately adjacent to the grave. DNA identification was accomplished using one of the teeth. All bone elements found had been heavily modified by carnivores, leaving midshaft fragments of many long bones, as well as tiny fragments of cranial bones.

A fragment of one of the right forearm bones, the right ulna, had evidence of a healed fracture, with a swollen callus indicating poor alignment of the bone; this coincided with the medical history of the victim. The pelvic fragment revealed a wide sciatic notch, characteristic of females. That, along with the small size and lack of muscularity, initially indicated that the remains were female. Court testimony centered on opinion regarding whether all the remains were from one individual and whether the damage to the bone was perimortem trauma or postmortem scavenging.

***Figure CS6.1.1*** The nearly empty grave was located by a cadaver dog.

***Figure CS6.1.2*** The area surrounding the grave was searched by state police and warden service personnel using two cadaver dogs, followed by a shoulder-to-shoulder search.

***Figure CS6.1.3*** All materials located were flagged, mapped using a total station, and recovered; most were found within 50 feet of the grave.

***Figure CS6.1.4*** Prior to excavating, the leaf cover was removed and examined carefully.

***Figure CS6.1.5*** Midshaft fragments of long bones.

***Figure CS6.1.6*** Tiny fragments of cranial bones.

***Figure CS6.1.7*** Right ulna fragment showed evidence of a healed fracture.

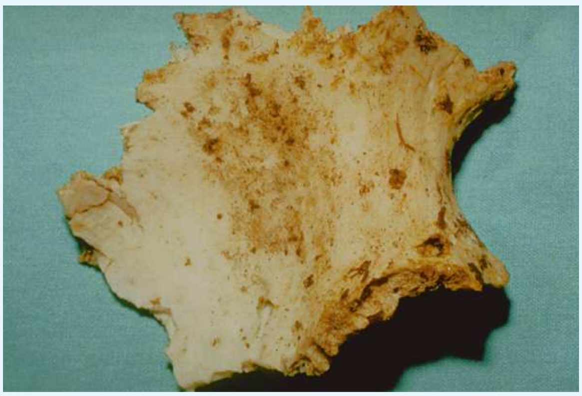


***Figure CS6.1.8*** Pelvic fragment revealed a wide sciatic notch (right side of image).

All sediment removed from the grave is screened to search for additional remains and evidence. If the grave matrix is mud rather than dry soil, a water screening process may be necessary. In skeletal cases, small bones are easily missed visually; screeners should be experienced in identifying such materials. At regular intervals, photographs should be taken of the excavation process and the excavation may be videotaped. Recall what we discussed in Chapter 3 regarding documentation of a crime scene. The same considerations and procedures apply in clandestine graves. If at all possible, the body or skeleton should be completely exposed prior to removal. In addition, the original grave perimeter, walls, and floor must be inspected for impressions of tools or footprints. If the remains are very fragile, they may be strengthened with preservatives or splints. The body is removed to a body bag placed beside the grave. Following another pass by the metal detector, the base of the grave is excavated and screened, going down several more inches in case small bones, teeth, artifacts, or projectiles have become embedded in the sediment.

## 6.5 Are They Human?

Differentiating human from nonhuman animal bones and teeth is a critical function. Most laypeople can readily differentiate adult human from nonhuman skulls, but other elements are more difficult. The similar shapes of mammalian and avian long bones produce confusion among animals of similar adult size. Bear paws are notoriously similar to human hands and feet, particularly when they have been skinned and the claws are removed. Bones and teeth of immature humans and other animals can be particularly ambiguous. A newborn human skull, for example, consists of many bony elements that have not yet fused and are not readily recognized by nonspecialists. Anthropologists can usually determine whether remains are human or nonhuman on first sight, and they have access to reference collections for more difficult specimens.

## 6.6 Are They of Forensic Importance?

In most jurisdictions, skeletal materials found unexpectedly on private or public land are turned over to the medical examiner or coroner and then to a forensic anthropologist. Some of these cases turn out to be unmarked historic or prehistoric graves. Federal and state laws govern the final disposition of remains judged to be historic or prehistoric Native Americans. Some states have statutes regarding the handling of historic remains not known to be Native American. The forensic anthropologist can identify these nonmodern cases, usually by the appearance of the body and the grave and associated grave goods or coffin fragments. State-specific procedures are then followed, usually involving reburial.

## 6.7 Taphonomic Assessment of the Body in Its Environment

### *6.7.1 Taphonomic Context of the Remains*

The anthropologist will need to pay attention to the immediate environment and surroundings where the body is found, called the **taphonomic context**. These details help with interpretation of the condition of the remains, estimation of the length of time since death (**postmortem interval**), and figuring out whether the death took place there or somewhere else. It is particularly important to note environmental characteristics that affect how much heat has been reaching the body, as well as the amount of moisture or precipitation. Any covering on the body may affect heat and moisture, as will nearby water or the depth of a burial. Finding out about recent patterns of temperature or precipitation is necessary to estimate the postmortem interval.

### *6.7.2 Taphonomic Condition of the Remains*

It is critical to document the condition of the body, as doing so can provide clues about how long it has been there and what has happened to it since death. This is its taphonomic assessment. Although the anthropologist will also observe the condition of the remains in the morgue or laboratory, seeing the remains in the place where they are found is extremely helpful for interpreting postmortem processes. The anthropologist will assess the stage of decomposition, the amount of scattering and evidence of scavenger chewing, drying and bleaching by the weather and the sun, and other changes. Noting any change in the remains as the body decomposes or is affected by the environment is important for a thorough assessment. Taphonomic data, including input from other experts, can be used to estimate postmortem interval, reconstruct postmortem event sequences (such as movement of the body), and identify potential wounded areas of the body (which tend to attract insects disproportionately). The postmortem interval estimation should be given as a range, making it clear that such judgments are probabilistic and conditional.

## 6.8 Soft Tissue Examination and Processing

After the taphonomic documentation is complete, the remains must be processed for skeletal examination. In decomposed or partly skeletonized cases, some soft tissue examination may still be possible. Fingertips may be preserved enough for fingerprints. Sturdier and more internal soft tissues may yield information about age, sex, and medical conditions; in these cases, collaboration with a forensic pathologist may be necessary. X-rays and careful examination of soft tissue are necessary in many cases to locate embedded or hidden bullets or teeth. With fleshed or articulated infant or child remains, x-rays can reveal the presence of bone formation centers, which can easily be displaced and are difficult to identify when out of anatomical position. When washing or boiling material, care must be taken to screen for small bones or artifacts and to refrain from overprocessing the remains, which can destroy bone integrity.

## 6.9 Developing a Biological Profile

When the victim is unknown, the anthropologist plays a key role by developing a biological profile. Developing such a profile entails studying the remains, while noting generic characteristics of shape and size that may allow an estimation of age, sex, and population or ancestry. Stature is estimated by measuring total body (or skeletal) length or by extrapolating from long bone lengths. Unique antemortem characteristics of the individual that would have been known to family or acquaintances, such as a healed bone fracture or an unusual dental configuration, are also included in the profile.

The goal of developing a biological profile is to describe the individual in such a way that law enforcement or acquaintances can narrow the range of possible identities. It is important to stay in a middle ground and not be too specific or too general; for example, it may be better to use a broader range of estimated stature and age to avoid erroneous exclusions at the outset of the investigation. The scope can be narrowed in subsequent stages.

The process of developing a biological profile requires the use of statistical descriptions of various populations that have been studied previously and reported in the professional literature. Difficulty can be encountered if the victim is unusual, has mixed ancestry, or belongs to a population that has not been well studied. Recent international investigations in human rights and crimes against humanity have pointed to problems with using U.S. standards in non-U.S. populations and the need for population-specific studies, particularly for age and ancestry.

Human populations do not have fixed boundaries; they grade into one another. Hence, the ability to assign a set of remains to a specific age, sex, or ancestry can be significantly impaired if the individual is divergent or has unfamiliar characteristics. Size and muscularity are important indicators of sex, for example, but it is well known that some males and some females fall outside of the normal range for their genders, and some population groups exhibit greater size differentiation between sexes than others.

### *6.9.1 Estimating Age*

#### ***6.9.1.1 Growth and Development***

A forensic anthropologist must be familiar with dental and skeletal development at each stage of life, beginning with the fetus. Size is used as a common indicator of age in infants and children. The lengths of the long bone shafts, called **diaphyses**, can be compared to published tables of age-associated size or used in regression formulae to extrapolate stature. Obviously, such estimates are imprecise due to the range of variation of size in children and should be reported as ranges.

The skeleton is formed by the development and growth of ossification centers, which gradually replace cartilage. In long bones, for example, bony tissue develops from a set of three main ossification centers: the shaft or diaphysis, and an **epiphysis** at either end. These three centers will ultimately grow together when the individual reaches full size. The timing of the formation, growth, and ultimate fusion of these and other ossification centers is patterned, depending on age, sex, bone element involved, nutritional and hormonal status, and individual variation. By the time a fetus is fully developed into a newborn, approximately 405 ossification centers are present. When an individual reaches adulthood (generally by his or her mid-20s), that number decreases to about 206 fully formed bones.

Patterns of bone development differ somewhat in males and females, with females developing a little earlier than males on average. Bone development sequences and timing also differ slightly from one population to another. Even within well-nourished, homogeneous populations, bone development may differ significantly from person to person. Thus, age estimates should always be expressed as ranges and should utilize as many indicators as possible for a single set of remains.

Humans, like other mammals, have two sets of teeth: the **deciduous dentition**, so named because it is shed in childhood, and the **permanent dentition**. A human child has 20 deciduous teeth; each quadrant has two incisors, one canine, and two deciduous molars—a dental formula of 2.1.2. Most human adults have 32 permanent teeth; each quadrant has two incisors, one canine, two premolars, and three molars—a dental formula of 2.1.2.3.

Tooth development begins in fetal life with formation of the deciduous tooth crowns within sockets or crypts. Beginning usually around the sixth month after birth, the deciduous teeth begin to erupt. Meanwhile the permanent teeth begin to form underneath the deciduous dentition. By about the sixth year, the deciduous front teeth begin to be lost and the permanent teeth erupt to take their place. The last teeth to erupt are the third molars, often called wisdom teeth, that begin to emerge in the 18th year in about 70% of the population. Many people have one or more third molars that never form (**agenesis)** or never erupt.

The patterns of tooth development, like those of bone, differ slightly by sex (females develop a bit earlier) and by population. The ranges of variation tend to overlap a great deal. Some dental traits are common in some populations and rare in others. Individuals of Asian or Native American ancestry, for example, commonly have a trait called shoveling, whereby the anterior teeth are slightly thicker (ridged) around the margins of each tooth on the tongue side. However, this trait is not uniform or universal in these populations, and members of other groups occasionally have it.

The numbers of skeletal collections that include children with documented ages at death are few; thus, our knowledge of population differences in bone and tooth development is somewhat limited, although the broad patterns are well known. There are comprehensive radiographic or x-ray studies that are more extensive because they involve living subjects. It is important to note, however, that **macroscopic** (non-enhanced visual) and **radiographic** (x-ray) standards of bone development differ from each other. Stages of **epiphyseal union**, particularly when bones are partly or recently fused, have a different appearance in x-rays than they do to the naked eye.

Standards for dental development tend to be slightly more precise in estimating age in children, particularly young children, than are those for bone development; hence, forensic anthropologists will generally emphasize dental standards in prepubescent remains. However, it is important to evaluate the entire set of indicators, dental as well as osteological, rather than depending on only one or two.

#### *6.9.1.2 Age-Related Changes in the Adult*

The bony skeleton is not fixed at adulthood; it changes continually until death, balancing the building and replacing of bony tissue at the cellular level. In general, **bone density** reaches a peak in the 20s and stays fairly high in the 30s, but begins to decline in the 40s. Females experience a fairly precipitous bone density drop around menopause; this decline levels off in most women after the age of 55 or 60 but continues to decline. Adult males over the age of 40 experience a gradual decline into old age. A minority of individuals suffer serious bone density loss (**osteoporosis**), which is more common in females and more prevalent in some populations.

Bone density depends on factors other than age and hormonal status. Weight-bearing exercise and good nutrition (particularly calcium, magnesium, and vitamin D intake) can minimize bone loss in many individuals. Bone density can be observed macroscopically, radiographically, microscopically, or via **bone densitometry**.

Macroscopic assessment is very general, requires experience, and relies on evidence of the thinning of the outer dense bone layer (**cortical bone**), reduced concentration of **trabecular bone** or spongy bone, **remodeling** (changing bone shape), and evidence of fractures. Radiographic methods depend on similar observations and are done using x-ray images. Such observations are not standardized, however. Bone densitometer assessment, on the other hand, is standardized by site, sex, age, and population. Microscopic measures of bone density have also been standardized for some populations by using a microscope to view a fixed and decalcified thin section of one of the major long bones and counting bone development structures called **osteons** and osteon fragments; these are cellular structures that increase in number with age.

It is also common to see some deterioration in joint integrity connected with use or wear and made worse by inflammation. This is related to the reduction in bone density after the age of 40. The resulting condition, **osteoarthritis**, tends to affect the spine and joints that are overused due to occupation or frequent patterned activity. It is infrequently seen before age 40, and varies a great deal among individuals. Osteoarthritis is significantly different from other forms of arthritis, such as **rheumatoid arthritis**, which tends to affect younger individuals.

One of the most reliable indicators of adult age is the **pubic symphysis**. The pubic symphysis is the area on the pelvis where the right and left pelvis halves join in the front of the body; it constitutes a flattened area at the end of each pubic bone, with a band of cartilage joining the two symphyseal faces. With age, these surfaces change from billowed to more flattened and rimmed. The changes have been divided into age- and sex-associated stages. Several published standards exist. The older the individual, the broader will be the estimated age range, however.

Standards have also been published for age-related changes in the end of the fourth rib nearest to the breastbone or sternum. When ribs are fragmented, identification of the fourth rib is more difficult. With age, the bones of the braincase or **cranium** tend to fuse together along the **suture** connections between them. Generally, older persons have more fusion, but the range of variation is great for older individuals and not precise. Nevertheless, cranial suture closure may be appropriately used as one of several measures, and occasionally is the only measure available in fragmentary remains.

As a person ages, wear and tooth loss affect dentition. These processes are, however, dependent on dietary practices, dental hygiene, and genetic background. Although population standards have been developed, application to individual dentitions is problematic.

### *6.9.2 Determining Sex*

Along with many other animal species, male and female humans differ by size, with males being larger on average. **Sexual dimorphism** is the term for the differences in size and shape between the sexes. Size is an indicator of sex, but so are muscularity, overall size, and the presence or absence of certain traits. DNA methods can produce very accurate determinations of biological sex.

**Gender**, the psychological and sociocultural attribution of sex, may be different from **biological sex**, which is based on genetic and hormonal differences. In fact, there are some rare genetic traits that make gender and observed differences in sex characteristics ambiguous. In forensic anthropology, although the ultimate goal is to discover identity (including gender), the initial step is the assessment of biological sex, not gender. The attribution of biological sex to skeletal remains using size, shape, and the presence or absence of skeletal markers is inexact. All methods are limited by the fact that there is some morphological overlap between males and females. It is well known, for example, that males are, on average, taller than females when the entire population is described; however, the ranges of size overlap greatly, and individual males and females may deviate from those tendencies.

At puberty, when circulating sex hormones increase greatly, skeletal morphology between males and females becomes more different. Prior to puberty, although differences exist, they are so small that forensic anthropologists do not attempt to assign sex in those cases. After puberty, differences increase, and the accuracy rate is well over 90% in sex attribution within well-studied populations. The skull and pelvis are the most sexually dimorphic skeletal areas, although it is better to examine the entire skeleton for indicators. The shape of the pelvis is critical for giving birth and enabling upright posture and locomotion. Both purposes are central to evolutionary success and under strong influence of natural selection. The bowl-shaped human pelvis balances and sustains the weight of the upper body to permit upright posture and efficient movement. The female pelvis has additional breadth and increased diameter of the pelvic inlet and outlet, enabling the infants of our relatively large-brained human species to pass through the birth canal. Associated female traits include a broad, shallow **sciatic notch**; the U-shaped **subpubic angle**; and a well-developed **ventral arc**.

The typical male skull tends to be larger with greater muscularity. It also tends to be more robust at areas of muscle attachment and biomechanical stress (brow ridges, chin) and more right-angled at the lower jaw, and it exhibits larger joint surfaces where the lower jaw or **mandible** connects to the braincase or cranium, and where the head connects to the top of the spine.

The **postcranial** (below the skull) skeleton is, on average, larger in males. The male tends to exhibit larger weight-bearing joint surfaces (e.g., the size of the hip ball and socket), more accentuated areas of muscle attachment, larger diameters of long bones, and greater stature. These traits vary between populations, though, and are related to nutritional status and behavior (e.g., weight-bearing occupations, strength training). No morphological indicator of sex is perfect. The best approach is to assess the entire skeletal pattern in the context of what may be known about the person or the population.

### 6.9.3 Estimating Population Ancestry

#### 6.9.3.1 The Concept of Race

Humans are a single species. The fabric of a single, shared genetic heritage extends throughout and varies continuously across all populations. There are no absolute physical or genetic reproductive barriers, even between the major human groups. All definitions of race are socially constructed typologies, with little biological basis. Populations exhibit much more variation within themselves than exists between groups. Although regional populations, when viewed as a group, may appear to share more morphological traits with each other than with distant groups, individual group members do not necessarily exhibit all the expected traits, and do not fit into the box created by the racial definition. Decisions about population boundaries are arbitrary, and group membership is ultimately fluid.

Thus, the attribution of population membership based on skeletal characteristics is difficult and often impossible due to the complexity of human mating and migration patterns. Our categories of human populations, sometimes termed **races**, are in fact socially constructed and arbitrary, without an empiric biological base. It may be possible to differentiate large populations from one another statistically based on sample morphology, but individual morphology frequently does not match the central tendency of any of our population reference samples, and population reference samples may or may not reflect social group membership, which can be a matter of personal choice or happenstance.

When the forensic anthropologist examines an unidentified body, the first task is to tease out a profile of biological and morphological characteristics from the details of the skeletal shape and size. The goal is to reduce the possibilities for group membership (age group, sex, or population) in order to increase the chances for identification. It is an exercise in statistics, sociocultural context, and judgment, and is not at all exact. Because the goal is to place an individual within a modern sociocultural matrix, the methods should utilize comparable reference populations. The United States has only a handful of well-known skeletal collections (or reference databases) with reliable antemortem information (i.e., known age, sex, and ancestry). Each population has its limits. Data analysis on World War II and Korean War casualties, for example, tends to emphasize young males, mostly European-American and African-American, born in the first third of the 20th century. Some reference populations are American (such as the Terry Collection at the Smithsonian Institution) or European (such as the Hungarian fetal samples studied by Fazekas and Kosa). There are a few modern forensic collections and databases, including, for example, the University of Tennessee Forensic Database.

It is essential to point out that skeletal morphology is produced by both genetic and non-genetic factors. This is true of both traits that can be measured (**metric traits**) and traits that are described as present or absent (nonmetric traits). So, making attributions of race or ancestry is particularly problematic.

Modern scientific methods of ancestry assessment have utilized various reference populations to develop statistical methods based on measurements or discrete trait frequencies. Each method focuses on a specific study population and develops a technique that works reliably within that study group. The application of the method to an unknown forensic case assumes the unknown individual fits the parameters of the study population, at least in general terms.

Many methods exist for forensic ancestry attribution, most of them using the skull. Metric statistical methods generally require that a prescribed set of measurements be made and plugged into a formula. For example, one method assesses facial flatness utilizing a specialized instrument called a **simometer**. It includes several measurements of the upper face and produces a numeric value that falls on either side of a sectioning point—thus, pointing to one of two populations being compared.

Observations of nonmetric traits can be used additionally (or alternatively). For example, Western European ancestry is frequently associated with facial morphology that includes a pinched nasal bridge and a narrow nasal opening, whereas in Asian populations and Native American populations, the nasal bridge is more apt to be flattened and the nose broader. However, no single trait should ever be used as the basis for a decision about ancestry; rather, the entire complex of traits and metrics should be assessed. The level of experience of the forensic anthropologist with the regional population within which he or she practices is critical.

### *6.9.4 Estimating Stature*

The estimation of living height or **stature** is not as straightforward as most people believe. First, stature is not a fixed trait. Adult stature changes (shrinks) from morning until night and over the course of the lifetime. The accurate measurement of living stature in an individual is actually a range. Second, stature measurement is frequently done incorrectly, resulting in fairly dramatic errors that can become incorporated into personal information. Missing person reports may include only a rough estimate of height. Interestingly, research has shown that American men tend to exaggerate their height on their driver's licenses by as much as 1 or 2 inches. Thus, the probability is fairly high that recorded statures will be inaccurate, particularly for males. Stature can be calculated for decomposed or skeletonized remains using several reliable methods. First, if the body is still essentially complete, the length can be measured, keeping in mind that the loss of muscle support will loosen joints and lengthen the body somewhat. If a body is skeletal and the joints are no longer held together with soft tissue (**disarticulated**) but some long bones are present, stature can be estimated using formulas that have been developed.

#### *6.9.4.1 Allometry*

When remains are incomplete, estimates of stature are done by extrapolating from the lengths of individual long bones, or combinations of long bones. This is done by using formulas developed for reference populations of known stature, such as military casualties or modern forensic case databases. The ability to estimate stature from long bone lengths depends on the presence of patterned and proportional relationships between the sizes of body parts, a concept called **allometry**. Taller people tend to have predictably longer bones. Allometric relationships between bone elements are systematic but not exact. They differ from population to population and from individual to individual. Individuals in any population may or may not conform to the central tendencies. Stature formulas usually specify a presumed ancestral population, such as "African-Americans." They also require the application of particular measurements of skeletal elements. Forensic anthropologists are trained how to perform these specialized measurements of the bones, called **osteometry**. Standards exist for how and where to measure each bone element. It is critical when applying stature formulas that the measurement is done exactly the same way as was done for the reference population. The resulting estimate is reported as a range.

## 6.10 Identification

### *6.10.1 Issues in Identification*

Identifications are often based on visual identification or on circumstantial evidence, such as clothing, location, or pathological condition. In cases of suspicious death, most medical examiners and coroners require **positive identification**—that is, identification beyond a reasonable doubt. In practice, such identification requires a match using one or more of the following legally accepted techniques: DNA analysis, fingerprints, dental records, x-rays, or a uniquely identifiable medical apparatus such as an artificial joint.

Occasionally such an identification process begins when the anthropologist or pathologist documents a unique anatomic feature (such as a congenital defect), evidence of a medical condition or surgical procedure, or bony changes associated with certain activities or occupations, but the presence of such characteristics, while indicating a probable identification, is not enough for a positive identification in many U.S. jurisdictions.

Another procedure that sometimes generates a lead to a possible identification is **facial approximation**, recreating the soft tissue appearance based on the shape of the bones of the face. Several methods are accepted, all of which require both technical and artistic skill. The skull, the cast of the skull, or a digital image of the skull can be used as a base, with soft tissue layers added (sculpted with clay or added digitally to an image) according to the presumed ancestry and the average tissue thickness at multiple points. Alternatively, a drawing is produced using a two-dimensional slide image of the skull and standard, multisite soft tissue thickness standards.

Although these methods sometimes produce striking results, they also have significant limits and are not a means of positive identification. Many facial features have a cartilage rather than a bony base—for example, the tip of the nose or the ears. Second, features commonly associated with an estimated population ancestry may or may not have actually been present in the victim, characteristics such as hair type or skin color for example. Third, the average tissue thickness will be an underestimate for persons with significant amounts of body fat. Key descriptive features such as hair length, facial hair, and glasses often must be guessed at. Electronic methods are easier than actual sculpting because such characteristics can easily be added or subtracted. Recently, standards of tissue thickness have been expanded to include American children. Sidebar 6.2 describes one tool that have been developed to help identify remains.

### SIDEBAR 6.2. CURRENT EVENTS: NATIONAL MISSING AND UNIDENTIFIED PERSONS SYSTEM

Forensic anthropologists' cases are often those in which the death occurred many years, or even many decades ago. Until recently, such cases might never be identified. Because most death investigations are largely handled by local officials, there have been very few national resources for linking information about unidentified remains across jurisdictions or across state lines. However, the U.S. Department of Justice, Office of Justice Programs, has worked with many stakeholders to develop a relatively new, online system, the National Missing and Unidentified Persons System (NamUs), for reporting and linking data about unidentified remains to data about missing persons (see www.NamUs.gov).

Using this system, medical examiners' and coroners' offices can now report unidentified remains that are found in their jurisdiction. Forensic anthropologists can be authorized by the medical examiners and coroners they work with to post information as well. Likewise, police and medical examiners or coroners can post information about missing persons cases. The system can search for links between the unidentified and missing persons according to filters set up by users. Members of the public have access to much of this information and can themselves perform searches for links or suggest corrections or additions of information about missing persons.

Because many of the unidentified are skeletal remains, forensic anthropologists are often the ones who develop the biological profile to describe the remains. Based on the skeletal evidence, they suggest the sex, age range, probable ancestry, stature, and indications of medical history. The NamUs system allows the addition of photographs and x-rays, facial approximations, and information about personal effects found with the remains. In many cases, samples are taken to develop and place on file a DNA record for the unknown remains, which can potentially be matched with a sample related to a missing person.

### 6.10.2 Individuation and Identification

A description of one or more individual characteristics may help narrow the number of possible identities for an unknown set of remains. These may include evidence of medical conditions, congenital defects, handedness, and other markers of occupational stress. The body may have unique or unusual features that family and friends were aware of. An anthropologist may also observe features that may never have surfaced. A **congenital anomaly** such as a cleft palate may be documented in a medical record or may have been apparent to others. Other types of anomalies such as an extra lumbar vertebra may not have been noticed.

Antemortem medical conditions or disease (**pathology**) likewise may or may not have been known; for example, evidence of previous surgeries may include a surgically implanted apparatus, possibly with a unique identification number. On the other hand, evidence of bone inflammation or infection may or may not have produced clinical symptoms that are described in a medical record. Child or other domestic abuse may be revealed by the combined presence of healed and partially healed patterned injuries.

Despite suggestions in the popular media, the evaluation of **markers of occupational stress** is neither straightforward nor, in most cases, possible for most forensic cases. Individuals rarely maintain the same occupation throughout adulthood. Further, similar bone changes may be produced by more than one activity. Right- or left-hand dominance can often be ascertained, however, at least in individuals who exhibited that dominance behaviorally, and unusual or particular patterns of use or wear may suggest certain repetitious actions that can be helpful in narrowing identification possibilities.

### 6.10.3 Levels of Certainty

An anthropologist may contribute evidence toward making an identification, although the legal authority to make that identification rests with the medical examiner or coroner. Evidence often falls into one of three levels of certainty. The lowest level is *possible*, where the biological and medical profile for this set of remains is consistent with the characteristics reported for a given individual. The middle level is *probable*, where it is more probable than not that this individual is so-and-so. This level often includes circumstantial evidence such as identifiable clothing, the presence of a medical condition, or an identification card. The third level is *certainty*, beyond a reasonable doubt. This level is generally the standard of practice in trauma in the United States and includes identification by fingerprint, x-ray match, dental match, or DNA match.

## 6.11 Trauma

The legal authority to determine cause and manner of death rests with the medical examiner or coroner; however, the anthropologist often contributes critical evidence for these determinations, particularly in the interpretation of skeletal trauma and judgments regarding the timing of the trauma. Human remains frequently exhibit signs of **antemortem trauma** (healed or healing prior to death) and **perimortem trauma** (occurring at or around the time of death). By noting the presence of active or previous bone remodeling (e.g., formation of a bony scar or **callus** at the site of a fracture), the anthropologist can assign a traumatic injury to the antemortem period.

Most remains examined by forensic anthropologists have an extended postmortem period and are decomposed or skeletonized. Such remains may undergo postmortem modification by a wide range of agents, such as carnivores or transport by flowing water, which may damage bone. This taphonomic damage is not related to the cause of death and must be differentiated from perimortem trauma by noting the patterns of bone breakage in relation to moisture and fat loss, differential staining on fracture margins, and signature modifications of scavengers, plants, or geological processes.

Bone damage with no signs of healing, which apparently occurred when the bone was still fresh and for which a taphonomic cause can be ruled out, is described as perimortem trauma. It is not possible to be precise regarding whether bone damage occurred just before or just after death. Unlike soft tissue, bone does not exhibit a detectable vital reaction without several days of healing time.

Bone damage is conventionally divided into **blunt force** or **sharp force trauma** categories, depending on the presence or absence of cut surfaces. Blunt force damage produces impact marks or fractures and can fragment bone. The force can be delivered at great speed (e.g., gunshot) or slower speed (bludgeoning by hand with a heavy object); these can often be differentiated by the amount of warping of the fragments, termed **plastic deformation**, which is more likely with slower loading. In both blunt and sharp force injuries, the pattern of impact scars, fractures, or cut marks can sometimes indicate object shape (e.g., head of a hammer), trauma type (e.g., frontal motor vehicle impact), or weapon class (e.g., single-bladed knife).

A **gunshot wound** is a special form of blunt force trauma. Firearm projectiles frequently create signature patterns in bone, particularly in the skull. An anthropologist will generally reconstruct a skull shattered by gunshot in order to evaluate the injuries. With many gunshot wounds, it is possible to differentiate the entrance from the exit by virtue of inward beveling on the former and outward beveling on the latter. Due to the relatively slower speed of the radiating fractures compared with the projectile speed, combined with the fact that fracture lines are halted upon encountering previous fracture lines, it is frequently possible to determine the sequence of multiple gunshot wounds.

In each case, an anthropologist looks at the pattern of antemortem and perimortem injury throughout the skeleton to render an interpretation about cause, timing, trajectory, and weapon characteristics. Taphonomic damage must be excluded. With many suspected instances of trauma it is necessary to examine bone damage microscopically to rule out postmortem modification. It is possible for different agents of bone modification to produce similar types of damage, a concept known as **equifinality**. These mimics can generally be differentiated, however, by analyzing the pattern throughout the body rather than focusing on a single site.

## 6.12 Documentation and Testimony

A forensic anthropologist is held to high standards of procedure and documentation. The chain of custody document, indicating who had possession of each item of evidence from the time of recovery until its use in court, must be clear. All examination procedures should be documented carefully. The forensic anthropology record should, in most cases, include a full range of anthropological measurements and determinations, although the formal report format requested in specific jurisdictions may be abbreviated. It is recommended that the basic forensic anthropology report include five components: (1) chain of custody, (2) taphonomic assessment, (3) biological profile (age, sex, ancestry, stature, anomalies, pathology), (4) identification characteristics and interpretation, and (5) description of trauma.

The forensic anthropologist is often asked to testify as an expert witness in court, offering opinion testimony regarding his or her findings. It is essential that anthropologists uphold the principle of scientific neutrality and objectivity, regardless of whether they testify for the prosecution or the defense. **Scientific certainty** is generally restricted to levels of 90% or higher for determinations regarding biological profile, but the standard is much higher than 99% for individual positive identifications. **Scientific probability** is greater than 50%, generally between 67 and 90%. In many cases, the level of certainty is derived from the reference population with which a particular method is developed and tested. The appropriateness of the reference population, the method, and the conclusions may all be challenged in court.

## Chapter Summary

Forensic anthropologists are key members of the death investigation team. They frequently participate in, or help coordinate, recoveries of remains that are decomposed, burned, or skeletal. Forensic anthropologists generally work as consultants to medical examiners or coroners or to law enforcement. Their examinations complement the work of the forensic pathologist in the assessment of identity, trauma, and circumstances of death. In some of the larger jurisdictions, medical examiner offices may include a forensic anthropologist on staff, but most forensic anthropologists work in academic settings where they also teach and do research.

The forensic anthropology examination and report include a taphonomic assessment of the body's condition in relationship to the environment in which it was found, often with an estimate of the postmortem interval. Careful inventory and examination of the body, including all of the skeletal elements, can lead to determination of the biological profile of an unknown individual, including age, sex, ancestry, stature, and pathology or anomalies. This profile can be used to describe the remains and seek an identification. In addition, the anthropologist assesses injury or trauma to the skeleton, which can be very useful to the medical examiner or coroner who must rule on cause and manner of death.

## 6.13 Review Material

### *6.13.1 Key Terms and Concepts*

Agenesis
Allometry
American Board of Forensic Anthropology
Ancestry
Antemortem
Antemortem trauma
Biological anthropology
Biological profile
Biological sex
Blunt force trauma
Bone densitometry
Bone density

Callus
Congenital anomaly
Cortical bone
Cranium
Deciduous dentition
Decomposition
Diaphysis
Disarticulated
Epiphyseal union
Epiphysis
Equifinality
Facial approximation
Forensic anthropology
Forensic archaeology
Forensic taphonomy
Gender
Gunshot wound
Macroscopic
Mandible
Markers of occupational stress
Metric traits
Morphology
Odontology
Ossification centers
Osteoarthritis
Osteology
Osteometry
Olsteons
Osteoporosis
Pathology
Perimortem
Perimortem trauma
Permanent dentition
Physical anthropology
Plastic deformation
Positive identification
Postcranial
Postmortem
Postmortem interval
Pubic symphysis
Races
Radiographic
Remodeling
Rheumatoid arthritis
Scavengers
Sciatic notch
Scientific certainty
Scientific probability
Sexual dimorphism
Sharp force trauma
Simometer
Stature
Subpubic angle
Suture
Taphonomic assessment
Taphonomic context
Total station
Trabecular bone
Ventral arc

### 6.13.2 *Review Questions*

1. What role does the forensic anthropologist play in a medicolegal death investigation? Differentiate the role of forensic anthropologist from those of the forensic pathologist and the medical examiner or coroner.
2. Recovery of human remains sometimes requires the skills of a forensic archaeologist. Name some of those skills and describe the situations in which those skills are likely to be applied.
3. The condition of the remains should be interpreted with reference to their taphonomic context. What does this mean and how does it affect the tasks of the forensic anthropologist?
4. When a forensic anthropologist generates a biological profile, what is that likely to include?
5. What factors may limit the ability of the anthropologist to attribute sex to a set of skeletal remains?
6. A child's long bones provide clues to age. What features of long bones are important in estimating age and why?
7. If bone growth and tooth eruption processes have ended, list several skeletal or dental features that can be used to estimate adult age. In very general terms, how precise are these methods?

8. The race concept is socially constructed and socially defined. How does this fact affect judgments the anthropologist might make regarding evidence of ancestry?
9. Stature can be estimated based on long bone length. What might limit the precision of these methods?
10. When a forensic anthropologist testifies as an expert witness, for which side might he or she testify? Explain your answer, including a discussion of the difference between science and advocacy.

## 6.14 References and Further Reading

### 6.14.1 Books

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# 7

# Forensic Entomology

## Chapter Overview

**Entomology** is the study of insects, so forensic or, more correctly, medicolegal entomology is the study of the insects associated with a body. We have touched upon the role of insects in death investigation in the previous two chapters; here we will explore it in great detail. Insects colonize a body almost immediately after death, assuming that the season and environment are appropriate. Their rate of development and the species dynamics over time can be used to accurately estimate the minimum time that the person has been dead, from a matter of hours up to a year or more postmortem. Insects can also be used to help understand many other factors about the death.

# Chapter 7
# Forensic Entomology*

*Gail S. Anderson*

## Chapter Outline



* This chapter is based on Chapter 9, "Forensic Entomology," by Gail S. Anderson, as published in the third edition of this text.

**SIDEBAR 7.1. CAREER PREPARATION AND EXPECTATIONS**

A forensic entomologist must have extensive training in entomology before he or she can begin applying that knowledge to a criminal investigation. Future forensic entomologists will begin their training with a bachelor's of science in biology, zoology, or entomology, usually followed by a master's degree and doctorate in entomology, preferably in forensic entomology, insect ecology, and taxonomy. Board certification in forensic entomology is available. As most active forensic entomologists today are university professors, their work includes ongoing research and training in the field. Graduate students frequently work under the supervision of a board-certified forensic entomologist.

## 7.1 Introduction

In the first few hours after death the forensic pathologist, a medical doctor specialized in forensic pathology, will use medical parameters to estimate the elapsed time since death. These include things such as cooling of the body (algor mortis), stiffening of the body (rigor mortis), and coloration change in the body (livor mortis). However, about 24 to 48 hours after death, most of these biological changes have been completed so they are of little value in estimating elapsed time since death. It is then that the police will turn to an entomologist.

Entomology can be used to estimate the minimum elapsed time since death from the moment of death up to a year or sometimes longer after death. Even in the very early postmortem interval entomology is still valuable, as flies lay eggs very shortly after a death, so although medical factors are usually used in those first few hours insect evidence can also be valuable. This is particularly true if only a body part is found, when medical parameters are of no value.

Forensic entomology is most well known for its value in time of death estimations, but studying the insects associated with a corpse can also reveal many other factors about the death, such as whether the body had been moved after death or has been disturbed, the presence or position of wound sites, whether the victim used drugs or was poisoned, and the length of time of neglect or abuse in living victims. Insects can also be valuable in the investigation of wildlife crimes and animal abuse. This subject is usually referred to within the broad context of forensic entomology, but as forensic means anything associated with the law it can encompass many other areas. The term *medicolegal entomology* refers to our more usual interpretation of the words—the use of entomology in death and abuse investigations—although these are not limited to human cases. The more recognized term, *forensic entomology*, will be used here, although this chapter is only concerned with the medicolegal aspects of forensic entomology. (For a discussion of career preparation for this field, see Sidebar 7.1.)

### *7.1.1 Importance of Estimating Elapsed Time Since Death*

Estimating elapsed time since death is extremely important, whether or not the death is criminal. In all deaths, it is of great importance to the family to know *when* their loved one died. People almost invariably refer to the death of a loved one in terms of time, such as "It was a week ago … a month ago … a year ago." If certain factors about a death are unknown, particularly the timing, it is very difficult for family and friends to grieve and therefore, eventually heal. This is particularly true when time has elapsed between when the person was last seen alive and when the person's decomposed remains are found. Understanding how, when, and why a person has died can help to give closure to family and friends and allow them to move on with their lives. Therefore, for purely humanitarian reasons, it is vital to be able to estimate elapsed time since death in all cases.

The timing of death may also have legal implications; for example, if a person had a life insurance policy that ran out at a particular time then it would be extremely important to determine whether the person died before or after the insurance ran out. Most importantly, however, when the death is a result of homicide, understanding when the victim died has a major impact on the success of the subsequent police investigation. It focuses police efforts, can support or refute a suspect's alibi, provides documentation of time since death, and helps in the identification of an unknown victim. In particular, time of death is vital in determining the victim's activities and associates in the period prior to the crime.

### 7.1.2 History

People are inclined to think that forensic entomology is a new forensic science due to its popularity in certain television shows in the last decade, but this is not true. Forensic entomology is probably one of the oldest forensic sciences around, with published writings dating back to the 10th and 13th centuries showing its use in murder investigations in China at the time. Even in its more modern form, forensic entomology is well over 150 years old. Modern forensic entomology began in France with the landmark works of Jean-Pierre Mégnin, including his seminal text, *La Fauna des Cadavres* (1894). This served as the first serious work in the field and initiated further research in Europe. By the end of the 19th century, interest had been piqued in North America, and the first research in the field was carried out in Quebec, Canada.

Although forensic entomology became quite commonly used in Europe throughout the 20th century, it did not really begin to take hold in North America until the 1970s. A single case in Canada was reported in the early 1960s, but then in the subsequent two decades a handful of entomologists in both the United States and Canada were asked by police to assist in homicide investigations. As police became more aware of the value of entomology at a crime scene, and as entomologists began to testify as expert witnesses, the science of forensic entomology grew.

In 1996, led primarily by the late Dr. Paul Catts and Dr. Lee Goff, the American Board of Forensic Entomology was born. In 2001, the European Association of Forensic Entomology (EAFE) was formally convened (http://www.eafe.org); in 2002, the very first North American Forensic Entomology Association Meeting was held in Las Vegas (www.nafea.net). Today, forensic entomologists are frequently called into homicide investigations in which the time of death is unknown, and entomology is commonly presented in court in expert testimony.

## 7.2 Estimating Minimum Elapsed Time Since Death

There are two methods to estimate elapsed time since death using entomological evidence. The first method is based on the predictable development of larval Diptera, or flies, primarily **blow flies**, over time. This form of analysis takes advantage of the known passage of time from when the first egg is laid on the remains until the first adult flies emerge from the **puparial** cases and leave the body, making it most valuable in estimating minimum time since death from a few hours to several weeks. The second method is based on the predictable **successional colonization** of the body by a sequence of **carrion** insects. This method can be used from a few weeks after death until nothing but dry bones remain. The approach used will depend on the age of the remains and the types of insects collected.

### *7.2.1 Dipteran Larval Development or Maggot Aging*

Certain species of insect depend on carrion or dead animal material to survive. Such insects are therefore very adept at locating a dead animal. Although, for the most part, such carrion insects survive on dead wildlife, humans are also animals, and from an insect's point of view a dead human is no different from a dead bear or a dead crow. Hence, insects colonize humans in exactly the same way they colonize a dead animal.

The first insects that are usually attracted to remains are "true flies," or Diptera in the blow fly family. These are the familiar large metallic-looking flies, often bright green or blue, that are frequently seen attracted to our garbage or outdoor picnics in the summer. Blow flies are attracted to a dead body for two reasons. Although a fly may look like an adult fly when it first emerges, its genitalia are not developed, so both male and female flies are attracted to a carcass for a protein meal to allow their genitalia to develop. This behavior brings to mind the many mosquito species that need to take a blood (protein) meal before they can develop eggs; however, the vast majority of flies attracted to the remains are mature females searching for suitable sites to lay their eggs.

As adults, blow flies feed primarily on sugary food sources (e.g., nectar) and protein (e.g., feces, carrion), but as maggots or larvae they need to feed exclusively on a dead animal. Therefore, female blow flies are extremely well evolved to locate carrion. They are strong flyers and can fly over many kilometers to remains. Because their maggots survive best in fresh bodies, the females have the ability to locate a dead body immediately after death. Although unnoticeable to a human, a dead body gives off a variety of chemical cues, such as odors, immediately after death. These cues allow a fly to locate a corpse very quickly; therefore, blow flies will arrive at a corpse very soon after death, as long as the season and temperatures are appropriate. Blow flies are not active during winter in much of North America as it becomes too cold for them. Also, blow flies are diurnal, which means that they, like us, are active during the day and are not active at night. This is an actual circadian rhythm, meaning that this behavior does not relate directly to darkness or even a drop in temperature but relates to the insect's awareness of time of day. Numerous studies have shown that blow flies become active in the morning and settle down at night; therefore, as long as season, temperature, and time of day are favorable, blow flies will arrive on a body very soon after death, often within minutes. If death occurs at night in otherwise favorable conditions, then no eggs will be laid until the following morning. This illustrates why it is so important for a forensic entomologist to always give a minimum estimate of elapsed time since death, because if death occurred at night then there might have been a considerable delay before the insects arrived. For example, if a fresh victim is found mid-afternoon and the insect analysis indicates that the eggs were laid on the body at around 8:00 a.m., that means the person has been dead since at least 8:00 a.m., but it is also possible that they could have died during the previous night.

Blow flies are attracted to a wound first, as blood is an excellent and easily obtained protein source for the maggots. Blow flies are so good at locating a wound that they can actually locate a venipuncture (needle mark) when it is no longer visible to the naked eye. In homicide victims, there are often wounds so these become the first site of colonization. If there are no wounds, the insects will colonize the natural orifices, as adult human skin is usually too tough for the very small maggots to break. Orifices are lined with a mucosal layer that is very moist and soft and much easier to break than regular skin. This means that if no wounds are present then the orifices will usually be colonized first.

Once the female fly has found a suitable spot to lay her eggs, she lays them and leaves. Her only maternal concern is to locate the most optimum location. After that there is no maternal care or interest in the fate of her eggs. The blow flies develop from egg through first, second, and third instars, or stages, of maggots, and they then enter a puparial stage before becoming adults. This follows a very predictable pattern that is primarily influenced by species and temperature. Insects are cold blooded, so their development is temperature dependent. As temperature increases they develop more rapidly, and as it decreases they develop more slowly. This relationship, at temperature optimums, is relatively linear, making it predictable. As the development rates are predictable, an analysis of the oldest insect stage on the body, together with a knowledge of the meteorological conditions and the microclimatic conditions at the scene, can be used to estimate how long insects have been feeding on the body and, hence, how long the victim has been dead.

The fly eggs hatch into delicate **first-instar** or first-stage maggots, which feed on liquid protein. After a brief period of time, primarily dependent on temperature and species, the first-instar larvae will molt to the **second instar**, shedding the first-instar larval cuticle and mouthparts. The second-instar maggot feeds for a period of time, then molts to the **third instar**, again shedding the cuticle and mouthparts of the previous stage. The third-instar maggot is a voracious feeder and frequently aggregates in large masses (Figure 7.1) that can generate a tremendous amount of heat. These masses can remove a large amount of tissue in a very short period of time. During this time, the *crop*, a food-storage organ in the foregut, can clearly be seen as a dark oval through the relatively translucent tissue of the maggot (Figure 7.1).

After a period of intense feeding, the third instar enters a non-feeding or wandering stage and leaves the body, looking for a suitable place in which to pupate where it will not be vulnerable to predation (see Figures 7.2 and 7.3). This can include the

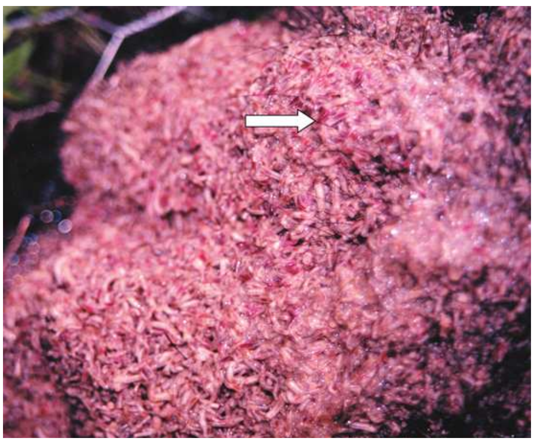

***Figure 7.1*** Large maggot mass on pig carcass. Insects are blow fly larvae (Diptera: Calliphoridae). Note foam created by metabolism and motion of insects and red crops clearly visible in maggots (arrow).

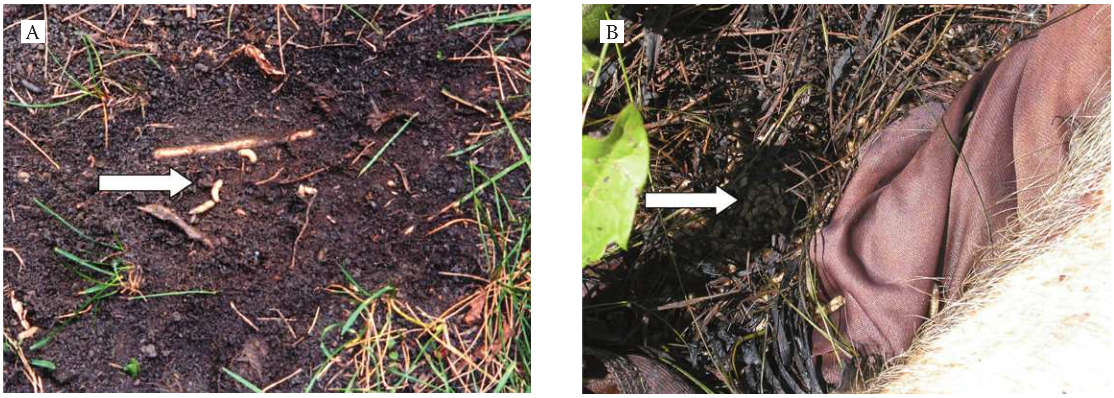


***Figure 7.2*** Nonfeeding third-instar larvae leaving food source in order to find suitable puparation site. (A) Crop no longer visible. (B) Large number of nonfeeding third-instar larvae burrowing into soil.

***Figure 7.3*** Blow fly (Diptera: Calliphoridae) pupae in leaf litter close to remains. They can also be recovered several meters from the body. Note variety of colors of pupae. The light pupae have only just pupated.

surrounding soil, carpet, or even the hair or clothing of the corpse. The maggots may burrow down several centimeters into the soil and may crawl several meters away from the remains until they find a suitable pupation site. From a forensic perspective this is very important as it means that the evidence has left the crime scene. Whoever does the evidence collection must be aware of not just the insects on the body but also those that have left the body. These maggots then pupate, just as a caterpillar forms a chrysalis. Inside the hard outer puparium, the pupa metamorphoses or changes into an adult fly, just as a caterpillar becomes a butterfly. When the adult fly emerges from the puparial case, it spends a few hours drying its body and expanding its wings, then it flies away, leaving behind the hard, dark puparial case as evidence that this cycle has been completed.

Newly emerged flies are of great forensic significance, as they indicate that an entire blow fly life cycle has been completed on the body. Once the fly is dry and can fly, an adult fly cannot be linked directly back to the remains. Even if collected on the body, it may just have arrived minutes before. However, the newly emerged insect cannot fly and so is inextricably linked with the remains. In the same way, empty puparial cases indicate that an insect has completed its entire life cycle on the body.

The fly's entire life cycle is predictable. It is heavily influenced by temperature, the major variable, in addition to species, nutrition, humidity, etc. When estimating time since death using blow fly development, there are several factors that must be known:

1. *The oldest stage of blow fly associated with the body*—The entomologist needs to be able to identify how far through the life cycle the insect has progressed. As development is highly temperature dependent, the insects that are furthest through the life cycle are the oldest, as they arrived first.
2. *The species of insect*—The entomologist must be able to identify the species of blow fly. Each species develops at a different rate, so the species must be determined. In most cases, the insects are identified by the entomologist based on morphological or physical features, although more recently DNA techniques have been developed to identify very young or damaged specimens.
3. *Temperature data*—Crime scene data are usually determined from government weather station data. A drawback to this approach is that bodies are rarely dumped close to a weather station, so the weather data may come from some distance from the crime scene and thus may not apply to the insects. Therefore, it is good practice to place a portable data logger at the scene and record scene temperatures for two to three weeks. These data can then be statistically compared with those from the weather station to determine whether temperatures at the scene are comparable with those from the weather station. A regression analysis can then be used to deduce temperature at the crime scene based on temperature at the weather station.
4. *Developmental data*—To age the insects, the entomologist must know the rate of development of the species in question, related to temperature. This information is obtained from published literature on the developmental rates of insects at different temperatures. Most entomologists develop such data for their own local species, and consequently there is a large body of literature on insect development rates.

When all four of the above pieces of information are available, the simple question is how long does it take this species to reach this stage, under these conditions? The answer might be, for example, at least seven days, in which case, the victim would have been deceased for at least seven days.

It is important to note that in most cases, forensic entomology will only *estimate* a minimum elapsed time since death (see Case Study 7.1 and Case Study 7.2). The science of forensic entomology is based on estimating the length of tenure of insects on a body, rather than the actual time of death. Death precedes insect colonization (except in rare instances), so the insects will indicate a time elapsed since death that is less than the actual time of death. It may be very precise, depending on how soon the insects colonized, but it will be less than the actual elapsed time since death. Although an entomologist can make an educated guess as to how long it took the first insects to colonize the body, this is an unknown. Eggs may have been laid within minutes, or they may not have been laid until the next day. Also, if the body was buried, wrapped, or killed in the depths of winter, insect colonization might be considerably delayed. Even when the condition of the remains and the scene suggests that a body would be colonized very shortly after death, unknown parameters may impact the rate of colonization.

### CASE STUDY 7.1: TIME SINCE DEATH

A person was killed violently in the heat of summer during the day and left fully exposed with large quantities of blood present. In such a situation, it would be expected that the remains would be colonized within minutes. I analyzed the evidence and estimated that the insects were a minimum of 48 hours old; however, I was not aware at the time that the remains were situated very close to a wasp nest (Hymenoptera: Vespula, *Vespa*). These wasps are predatory and feed on many things, including fly eggs. Flies did begin to lay eggs very shortly after death, but for the first 24 hours the wasps removed the eggs as they were laid. After this time, the vast number of eggs being laid overwhelmed the wasps' ability to consume them and some were left to continue to develop. It was these later insects that were collected by the police officers.

Had an attempt been made to estimate a maximum time since death based on the insects collected, the maximum time since death would have been underestimated by one day. This could have been dangerously misleading. The decedent had died three days prior to discovery, so the minimum elapsed time since death of *at least* two days, estimated by the entomologist, was still correct, although an underestimate. Therefore, it is always safer to give a minimum elapsed time since death, of which the entomologist can be sure.

### CASE STUDY 7.2: USING MAGGOTS TO ESTIMATE ELAPSED TIME SINCE DEATH

In a case in which two young women were found murdered, two sets of witnesses were presented in court. Two of the witnesses were young men who claimed they had seen the murders take place on May 3, and two were average citizens who claimed they had seen one of the victims alive on May 9. The insect evidence indicated that death had occurred on or before May 6 and had probably occurred several days prior to this time. This evidence supported the testimony of the two eye witnesses, who might otherwise have not been believed, and it refuted that of the citizens, who must have been mistaken about the date of the sighting. The entomological evidence resulted in the eye witness testimony being believed, and the defendant was convicted of two counts of first-degree murder and is currently serving life without parole for 25 years.

In many cases, the entomological evidence may be of great value in the actual police investigation but may never be required in court. In the case of a murdered young woman, her boyfriend rapidly became the chief suspect. Police believed she had been killed some three weeks prior to discovery, at a time when the boyfriend had no alibi. However, the suspect's friends claimed that they had seen the victim much more recently, when the suspect was out of town, providing him with an excellent alibi. Despite lengthy and repeated questioning, the friends stuck to their story; however, the entomological report clearly indicated that death had occurred three weeks prior to discovery. When faced with this scientific evidence, the friends recanted their statements, and the suspect confessed.

Entomologists usually rely on the minimum or average development rates of insects. Some insects in a cohort may take longer to develop; therefore, using a minimum ensures accuracy, although it may also underestimate the elapsed time since death. This is desirable, however, as this is not just an interesting piece of science, but information that in some cases can result in a person being imprisoned for life or in their judicial execution. It is therefore, very important to err on the side of caution. As such, entomological evidence will usually indicate that a person has been dead for at least a certain period of time. It could have been longer, but could not have been less. It is this date that the entomologist will stand on in court.

Time of death can be very valuable in a homicide investigation in supporting or refuting an alibi. When remains are found in an advanced state of decomposition and a person comes forward to say that he or she witnessed the killing, that person's testimony may not be believed, due to the length of time that has elapsed before the witness came forward. In many cases, there are two sets of witnesses, one claiming that death occurred at a particular time and another claiming that the victim was alive and well at a later date. The jury is then asked to give a subjective opinion on the veracity of the witnesses. Entomological evidence is not subjective; it is based on scientific principles, and although it cannot tell the court who is telling the truth it can frequently indicate who is lying.

### *7.2.2 Successional Colonization of a Body*

A dead body, whether animal or human, is a rich but limited nutritional resource that supports a rapidly changing ecosystem. As discussed earlier, the first insects, the blow flies, arrive very rapidly after death. As these insects feed, they change the carcass, and as decomposition progresses the body becomes less attractive to these early colonizers and more attractive to other insects. As the body decomposes, it goes through a sequence of rapid biological, chemical, and physical changes (see Case Study 7.3). These changes in decomposition attract a dynamically changing sequence of colonizing insects that continue to feed until there is no nutritional value left in the remains.

The sequence of insects that colonize depends on the nutritional changes in the body and is greatly impacted by geographic region, habitat, season, meteorological conditions, and microclimate, but the sequence is predictable within those parameters. This predictable and sequential colonization of a body allows an entomologist to estimate the tenure of the insects on the body and therefore the minimum time since death.

When an entomologist studies the large variety of insects found on the remains, the first step is to identify the species that are present at that time. As long as experimental data are available for the same geographic area and scenario, then the entomologist can say that the insects indicate that the victim has been dead for a certain period of time; for example, the entomologist might say that a victim has been dead three to five months. Then the entomologist will look at the evidence of insects that are no longer on the body, having left when the body passed the stage of decomposition that made it a suitable source of nutrition for that particular species of insect. This indicates that it is past the time frame in which these species normally are found on a body in this scenario, and the entomologist can estimate that the victim has been dead for at least that period of time. It might indicate, for example, that the victim has been dead for more than four months. Finally, an entomologist who is very familiar with the geographic area and general scenario might observe that the next group of insects to be expected is not yet present, further refining the estimate.

### CASE STUDY 7.3: USING INSECT SUCCESSION TO ESTIMATE ELAPSED TIME SINCE DEATH: THE EVIDENCE THAT WASN'T THERE

In the far north of Canada, mummified human remains were found under a waterbed in the basement of a home in late May. The insects on the body included many of the species that you would expect to find colonizing a body that has been dead for a long time. They included living insects, which indicated a minimum time frame, as well as the remains of insects such as empty puparial cases and cast larval skins, which indicated that some earlier species had been present but had now left the remains, further refining the estimate. This evidence all indicated that the person had been dead for many months. Because it was still too cold at that time of year for the insect season to have begun, the insects indicated that the remains must have colonized the remains the previous summer.

Of greater interest in this case, however, was not the evidence that was there, but the evidence that was *not* there. The evidence that was missing was any sign of the presence of blow flies. Now, you would not expect blow flies to be interested in a mummified body. They feed in fresh tissue. But, if the person had been killed the previous summer, you would expect blow flies to have colonized the remains immediately after death. Although there would no longer be maggots on the body once it became mummified, had they ever been there they would have emerged as adult flies and left evidence of their activity in the form of empty puparial cases that would have been found in the bedroom. As well, they would have removed most of the tissue and so the body would not have mummified. It is highly unlikely that people in the house would have not noticed the pungent smell of putrefaction. So clearly, there were never any blow flies on the remains. It would be tempting to say that they could not access the body, as it was inside a house, under a waterbed frame. But this makes no sense, as other species managed to find the body. Experiments have shown that such a scenario would result in a delay of several days before insects got to the body but would certainly not exclude them.

The lack of blow flies proved that the person did not die during the previous insect season, when blow flies would have rapidly been attracted but instead must have died before the insect season began the previous year, allowing time for the forced air heating in the house to mummify the remains. By the time the insect season began the previous year, the remains must have already been mummified and were no longer attractive to blow flies but still very attractive to the later colonizers. The killer later confessed and admitted to having killed the victim the previous March, several months prior to the start of the insect season, as the insects indicated.

It is important to note that using insect succession to estimate elapsed time since death is dependent on geographical and habitat-specific research data being available. You cannot use successional data from one area and apply it to a different area, as the species involved, their times of arrival, and their tenure on the remains are greatly impacted by geographic region, latitude, exposure, altitude, and habitat, to name just a few, and the actual colonization of the remains is also impacted by whether the remains are in an urban or rural area, inside a building or car, buried, hanging, or in water. This is why forensic entomologists around the world spend a lot of time conducting research in their own areas in a variety of situations.

## 7.3 Other Uses for Insects in Death Investigations

### 7.3.1 Indicating Whether the Body Has Been Moved

Under certain circumstances, insects can be used to understand many other factors related to a death scene besides elapsed time since death; for example, they can be used to indicate whether a body has been moved after death. A killing may occur on the spur of the moment, leaving the killer with a body that must be hidden in some way. The adult murder victim is heavy, difficult to lift, and frequently bloody, and the body may also be covered in excretory material, as sphincter muscles relax during violent death. For this reason, it is not uncommon for the killer to leave the remains at the death site for a period of time while going away to think about how to get rid of the body. The killer may return later, possibly with assistance and a vehicle, to dump the body, usually in some remote area. If the body has remained at the original site for any length of time, and the conditions are appropriate, insects will colonize the body. At first, the only sign of colonization will be blow fly eggs in the wound, the corners of the eye, and in the nostrils. When the killer returns, the insects will probably not be noticed. If they are observed, it is unlikely that the killer will consider them as evidence. If the killer is aware of the value of entomological evidence, he or she might try to remove the eggs, but it is unlikely that all the eggs would be removed. The killer will then move the body and dump it in a remote location to hide it, thus moving the insects from their usual habitat to a new area.

When the body is found at the dump site it will have attracted insects local to the area, but it will also have insects present that are older, carried on the body from the death site. These insects often are not consistent with the dump site habitat. They may be species of insects that are most commonly found in an urban area or in a forested area. If the dump site is very different from that, such as a very rural area or an open pasture, the forensic entomologist will be able to comment that the insects indicate that the body has been at the discovery site for a certain time frame (e.g., a minimum of six days) but also that previously it had been in a very urban environment for at least four days, for example. This indicates to the investigators that the victim has been dead for at least 10 days but that the remains were moved from the original death site about 4 days after death. It also indicates that the death site was in an urban area. If the victim is known to police then investigators may know the usual places that the victim may have frequented, and examination of these areas may lead them to further evidence that indicates where the death took place. As the killer went to great lengths to dump the body, the killer never expects the police to find it, let alone locate the original death site, which means it is often not well cleaned; it is common for police to find a treasure trove of evidence at such scenes.

### 7.3.2 Determining Whether the Body Has Been Disturbed after Death

It is not uncommon for a killer to return to the scene of the crime and disturb the remains (see Case Study 7.4). Killers return for a variety of reasons. They may go back because they were incapacitated by drugs or alcohol when the crime was committed and cannot remember if they committed the crime. Commonly killers return to the scene of their crime to fantasize about the killing, or they may go back to recover evidence they feel may incriminate them. If they disturb the body in some way, it might also disturb the insects. An entomologist may be able to estimate not

**CASE STUDY 7.4: DISTURBANCE OF THE BODY**

The remains of a man were found in a shallow grave in the Lower Mainland area of British Columbia. The careful police exhumation took several days. On the first day, the insect evidence appeared puzzling. The remains were skeletonized and were past the stage when blow flies would have been interested in the body, but the fact that they were buried and yet cleanly skeletonized indicated that blow flies had been major players in removing the bulk of the tissue much earlier. Yet, there were almost no empty blow fly puparial cases found in the carefully screened soil to show that this had taken place. Where had they gone? In very old burials such evidence may degrade and disappear, and the timing depends on soil type. Experience in this geographical area indicated that puparial cases could last for years in the soil but not as much as 25 years, whereas publications from much dryer areas suggest that blow flies can survive for decades and even centuries in different soil types. The victim was known to have been missing for less than a year, so the lack of empty puparial cases was a mystery. On the second day, however, very large numbers of puparial cases were found associated with the lower half of the body. This suggested that the upper half of the body had decomposed at the same site as the lower half, but had later been moved to a secondary position after skeletonization, perhaps because part had been exposed. The evidence suggested that the body had been reinterred several weeks after the original burial.

only minimum time since death, but also *when* the body was disturbed. It is probable that the killer will have developed an alibi for the time the murder was committed, but it is unlikely that the killer will have developed an alibi for the time when he or she went back to the scene. As well, in many killings, the police have a strong suspicion of the person who is responsible but not enough evidence for a warrant. If both the time of death and the time of disturbance are known and fit the activity pattern of the suspect, that may help to corroborate other evidence.

### *7.3.3 Locating the Position of Wounds*

Blow flies are the first insects to be attracted to remains and usually lay their eggs close to a wound, so that the first-instar maggots have access to liquid protein for nutrition. Once a body is in a state of advanced decomposition, it is often difficult to work out whether wounds were present. If the weapon does not strike the hard tissue, such as bone and cartilage, it may easily be missed, despite the fact that a wound in soft tissue alone can be fatal. A slit throat or a stab wound in the soft tissue of the gut could easily be missed. Insects, however, can locate a wound, no matter how small, because laying eggs close to a wound is a survival strategy that increases the chance of success of the female flies' offspring (see Case Study 7.5). Therefore, female flies are genetically programmed to be extremely efficient at locating a wound.

When a body is highly decomposed, we can look at the pattern of maggot colonization on the body. If the maggots began feeding at the natural orifices then it is likely that there were no open wounds. On the other hand, if the oldest maggots clearly began feeding in, for instance, the stomach area, and only much younger and smaller maggots are found in the orifices, then it is very probable that there was a wound in the stomach. It is not up to an entomologist to state that an area is

**CASE STUDY 7.5: USING INSECT ACTIVITY TO LOCATE WOUND SITES**

In a case that was originally considered to be a suicide or undetermined death, the body of a young woman was found several days after she had left home to go for a short walk. The remains showed large maggot masses in the chest region, as well as the palms of both hands. Unfortunately, a forensic entomologist was not called and no entomological evidence was recovered. The victim was interred and listed as an undetermined death. Sometime later, investigators showed photographs to Dr. Bill Rodriquez, a forensic anthropologist, who noted that the primary maggot activity was in the chest region and the palms of the hands, rather than the face. This strongly suggested the presence of wounds in these areas. In particular, the presence of maggots in the palms of the hands, an area rarely colonized by insects due to the tougher skin, suggested the presence of defense wounds. Based on this evidence, a court-ordered exhumation was performed and the remains examined again. When the body was reexamined, many stab wounds were identified in the chest region, as well as severe slashing to the hands that had almost severed one thumb. The case has since been reopened as a homicide, but it would never have been closed had an entomologist been called into the case at the beginning.

a wound site, but rather the forensic pathologist, who conducts the autopsy and is qualified to identify a wound and the weapon that caused it. It is up to the entomologist, however, to point out an irregular or atypical insect colonization pattern that might indicate a wound.

Caution must be taken when inferring wound sites from insect activity. For instance, it is often thought that the presence of maggot activity in the genital area of a victim indicates a rape. If the oldest insects on the remains are in this region, and the only other activity is clearly of a later date, this may indicate that a wound or semen was present at this site. However, experience has shown that if the genital region is colonized at the same time, or later than other areas, it may just be normal insect colonization. The orifices are also attractive colonization sites due to the presence of a mucosal layer, and they are quite normally colonized. Even the presence of the added attraction of semen is not necessarily indicative that a rape has occurred, as it may be the result of consensual sexual activity that is unrelated to the death.

It should be pointed out that if rape is suspected then a sexual-assault kit should be used to collect DNA swabs as soon as possible, as insects will remove this evidence rapidly. If the remains are placed in a morgue cooler with the intention of collecting the DNA evidence later, the evidence will frequently be destroyed by maggot activity. Although refrigeration will slow down insect activity greatly, if a body has large maggot masses they will generate a lot of heat so will take some time to cool down. In the meantime, vital evidence may be consumed.

### *7.3.4 Linking Suspect to Scene*

We discussed Locard's exchange principle in detail in the first chapter and we see it in action here. There have been several cases in which a criminal has unwittingly taken away entomological evidence from a crime scene which subsequently linked him or her back to the scene or victim (see Case Study 7.6).

**CASE STUDY 7.6: THE CASE OF THE MYSTERIOUS "FIBERS"**

One of the first published reports of forensic entomology in Canada describes how insects were used to connect a suspect to the crime. In 1963, a person broke into the house of an elderly man in order to rob him. The homeowner confronted the suspect and was brutally beaten, resulting in his death some days later. A suspect was arrested and searched. A Canadian bank note worth 25¢ was found in the pocket of the defendant, but it was simply a bank note that could have come from anywhere, as the defendant claimed. An examination of the note revealed that there were several unusual "fibers" stuck to the bank note. An entomologist was asked to look at the fibers. Instead of fibers, they were found to be the hairs of a bumble bee. The investigation revealed that the elderly victim had kept his money in a drawer in his house. When this drawer was examined, a dead bumble bee was discovered. It was considered that finding bumble bee hairs on a bank note was very rare, so this was part of the evidence used in the defendant's conviction and subsequent execution. Today, one hopes that data would be collected to determine how common it is to find bumble bee hairs on bank notes to determine the probability of an innocent person having such notes. As well, depending on the specimen, it might actually be possible to perform a DNA analysis and determine whether the hairs came specifically from that bee.

In a case from suburban Chicago, a woman was raped by a man wearing a ski mask. The rape occurred in early to midsummer. A suspect was identified, and a search of his home revealed the presence of a ski mask. The suspect admitted to owning the mask but swore he had not worn it since the previous winter, months before the rape; however, investigators noticed that there were several plant parts on the mask, including cockleburs. A forensic entomologist opened the cockleburs and discovered that they contained live caterpillars. An analysis of their life cycle indicated that, in order to have collected cockleburs containing larvae of this stage, the mask must have been outside in the early part of the summer of the present year. When shown the evidence, the suspect confessed.

In another case, this time in Southern California, the body of a young woman was found in a rural area in late summer. When death investigators processed the crime scene, they found that they were all severely bitten by something. The bites were identified by a doctor to be those of the immature stage of a trombiculid mite, which is also known as a chigger. Although actually mites and not insects, they are often considered within forensic entomology. Chiggers are known to have a discrete geographic distribution and to leave very characteristic bites. When a suspect was developed and examined, it was noted that he also bore similar characteristic dermal lesions resulting from chigger bites. An extensive search of the region found that large numbers of chiggers were found in only a very narrow area between a cultivated field and the edge of natural vegetation—the very site of the crime scene. The defendant was found guilty of first-degree murder, based primarily on this entomological evidence.

### *7.3.5 Using Insects to Indicate Drug Use: Entomotoxicology*

They say that "you are what you eat." Carrion insects feed on the tissues of the dead body. This means that they also ingest all the toxins contained in the body at the time of death. This can include poisons and drugs. When a person takes a drug or poison,

### CASE STUDY 7.7: USING POLLUTION LEVELS TO IDENTIFY A BODY

In Finland, a young woman was found dead and it appeared impossible to identify her. No identification was found with her remains, and she was highly decomposed and extensively maggot infested. Toxicological analysis was not possible due to the extensive state of decomposition. A world-renowned forensic entomologist, Dr. Pekka Nuorteva, was called in to assist police. In earlier groundbreaking work, Dr. Nuorteva had found that it is possible to recover mercury from insects fed on fish from polluted waters. Nuorteva analyzed the maggots on the young women and found a very low level of mercury in them, suggesting that this woman had lived in an area that was much less polluted than the town in which she was found. The levels of pollutants suggested where she might have come from. When sketches of her face drawn by a forensic artist were exhibited in that region, she was identified.

unless it is immediately fatal the body begins to metabolize the drug. This process involves breaking the original drug, known as the parent drug, into its component chemicals, known as metabolites. These metabolites are then broken down further and eventually excreted. If a person dies after taking a drug, either due to the actions of the drug itself or for other reasons such as homicide, then depending on the length of time elapsed between drug consumption and death various levels of the parent drug and its metabolites will be present. Toxicologists usually analyze body samples in order to determine what toxins were present at the time of death and then interpret this to assist the investigators in determining how and why a person died, and what behavioral effects might have been expected at a certain time. For instance, it may be important to know what the level of drugs was in a person two hours before their death. Toxicologists, therefore, need to be able to identify the toxin, then quantify it; in other words, they need to know how much of each parent drug and metabolite are present. This is only possible, however, when the body is fairly fresh. (See Case Study 7.7 for an example of a case in which ingested materials became important.)

Once the body begins to decompose, the tissues used for drug analyses such as blood, liver, kidney, etc. begin to degrade and eventually decompose entirely, making them useless for drug analyses. However, the insects feeding on the body, ingesting the tissue together with all the chemicals in it, are fresh in the sense that they are still alive. Therefore, insects, primarily blow fly maggots but also other insects, can make excellent alternative toxicological specimens that can be analyzed in exactly the same way that the toxicologist would analyze a piece of the human tissue.

There have been many studies and case histories worldwide that have shown that insects can successfully **bioaccumulate** ingested chemicals into their body tissue, allowing them to be used as toxicological specimens throughout much of the life cycle. This allows toxicologists to use maggots, pupae, empty puparial cases, and beetles to identify what the parent drug was and the identity of the various metabolites. In other words, toxicologists can perform a *qualitative* analysis and identify the chemicals. However, the results have been much less consistent when attempts have been made to *quantify* the drugs in the victim, to determine the amount of each drug or metabolite that was in the tissue based on the insect specimens. At this time, therefore, although an analysis of the insects feeding on a body can be very useful to identify *what* drugs were present, it is not possible to consistently determine the *amount* that was ingested (see Case Study 7.8).

**CASE STUDY 7.8: THE EFFECTS OF DRUGS ON INSECTS**

In what appeared to be a routine forensic entomology case, Dr. Paul Catts analyzed the insects from a young female murder victim in Washington State. The majority of the insects indicated that the victim had been killed about one week before discovery which fit with the known facts of the case. However, there was a single maggot that was much larger than the other maggots, indicating a time of arrival on the remains almost three weeks prior to discovery. This anomaly was explained when it was discovered that this single maggot had been collected from the nostrils and that the victim had snorted cocaine very shortly before her death, so this maggot alone had been feeding on very high levels of cocaine, speeding up its development.

Although insects can be valuable in understanding the drug history of a victim, the drugs themselves can have a serious impact on using the insects to estimate elapsed time since death. Drugs and other toxins impact our own metabolism and development in many ways. Drugs considered to be "uppers" speed up our metabolism, and those considered to be "downers" may act as sedatives. In the same way, many drugs can have an impact on insect development, either speeding it up or slowing it down, depending on the drug involved and the stage of the insect. Pioneering work by Dr. Goff in Hawaii indicated that many drugs can impact insect development, and the effect varies with drug and insect stage. Because drugs can have a significant impact on insect development, it is important to ensure that the entomologist is made aware of the information revealed in the toxicologist's report before submitting any analysis.

### *7.3.6 DNA and Insects*

No forensic science chapter would be complete without a mention of DNA. In the case of forensic entomology there are two quite different roles for DNA. First of all, DNA can be used in the usual manner to identify the insect. Insects have many morphological or physical characteristics that make them identifiable using carefully developed insect keys that allow an entomologist to go through each minute feature to identify the animal. Such identifications have been done for hundreds of years and are just as useful today as they were in the past, so in most cases DNA is not required to make a simple adult insect identification. However, DNA is useful in identifying an insect when specimens are broken or badly preserved such as in the reopening of a cold case or when eggs or very young maggots are recovered and preserved. In a good forensic insect collection, some maggots are preserved for later analysis and others are kept alive for rearing to adulthood for ease of identification, among other things. In some cases, though, particularly in older cases, immature insects have been preserved only. Later stage maggots do have some morphological features that allow identification, but younger stages and eggs usually cannot be identified. In these situations, DNA is valuable and much work has been done to identify many forensically important species. There is a second, much more exciting role for DNA in entomology, and that is using insects to retrieve DNA from the victim when the victim's DNA is no longer available. When maggots ingest tissue, the partially digested food is first stored in a crop or food storage organ which is part of the foregut. It is eventually utilized and digested. The material inside this crop is an excellent source of the host DNA, that is, the deceased victim in which the insects are feeding. Although, in the early days of DNA, a relatively large sample of fresh tissue was required in order to get an identification, today a sample can be as small as a few cells, and extremely degraded tissue can be used to extract DNA. Even with highly decomposed human remains, it is still possible to obtain DNA, so it would seem that the DNA in the insect's crop is of little value, but in some rare situations it can be vital. Suppose a killer murders his victim and hides the body somewhere, then hears that a "friend" has gone to the police and told them where to look for the body. The killer goes back to the scene and removes the remains. When the police arrive they find maggots that have fallen off the remains but no body. In the past, you could say that the presence of carrion maggots indicates that something was rotting there but it could just as easily have been a dead dog as a dead human. Now, though, with a DNA analysis of the maggot gut contents we can identify the species (e.g., human vs. canine) and can actually identify the victim if we have a comparison sample.

Even more interesting, perhaps, is the analysis of DNA inside blood-feeding insects. Many insects blood feed, including mosquitoes, bed bugs, and fleas. The interesting thing about bed bugs is that they occupy a room rather than a person, so anyone entering that room might get bitten. A burglar may rob a bedroom and take great care not to leave fingerprints and DNA around in the usual fashion, but he may be bitten by bed bugs that are later analyzed to prove he was in the room.

Although fleas are usually associated with the host and do not reside in a room as adults, they are constantly blood feeding and excreting partially digested blood in their **frass**, or feces, in order to feed their young who live on the ground, often in carpets. In the case of an interpersonal assault, a suspect may shed frass into the scene which could potentially be used to obtain DNA.

### *7.3.7 The Use of Insects in Investigating Abuse or Neglect Cases*

The insects used in forensic entomology analyses are those that feed on dead organic matter, but unfortunately it is not uncommon for living people and animals to have dead organic matter on their bodies (see Case Study 7.9). This can be in the form of an unhealed wound, a bed sore, gangrenous and dying tissue, or very poor personal hygiene. This material is just as attractive to carrion insects as a freshly dead body. Flies, primarily blow flies, lay eggs on the living person, and the resulting maggots feed on the necrotic material on the live person. This infestation of living human or other vertebrate animals with dipteran larvae is called **myiasis**. Despite the fact that this seems very revolting, in actuality the insects usually do no damage as they are feeding on necrotic material; indeed, they are, in fact, cleaning the wound. As such, they may actually help the victim by removing the dead tissue. Despite this, their presence is unwanted and incurs feelings of revulsion. Also, some species may begin to feed on living tissue, causing extensive damage.

Although these types of insects do not vector diseases in the traditional manner that a blood-feeding insect, such as a mosquito, does, they can mechanically transmit diseases just as a human does by touching something covered in bacteria and then touching food. This is why everywhere we go there are signs telling us to wash our hands frequently to reduce the risk of transferring disease to our food. Carrion flies feed on dead bodies and feces so they are constantly in contact with large quantities of bacteria, but they are also attracted to our food. They frequently walk on a decomposing animal and then walk on our food, transmitting the bacteria. This is why we protect our food from flies. In the same way, insects can also mechanically transmit bacteria to a wound, further infecting it.

**CASE STUDY 7.9: THE ABANDONED BABY**

In Hawaii, tourists discovered a live baby abandoned in dense brush close to a lake. The child was about 16 months old and was fully clothed, including a very soiled diaper. The child also had severe diaper rash. A number of first- and second-stage maggots of the oriental latrine fly were collected from the child's genitalia. Dr. Lee Goff was called into the case to analyze the insect evidence. From his extensive research in Hawaii, Dr. Goff knew that this is a species that colonizes dead remains within a few minutes of death but is not attracted to moving objects. It is also extremely attracted to feces. Dr. Goff was able to say, based on his own experiments in this region and on this species of insect, that the insects had been laid as eggs at least 23.5 hours before the child was recovered and that the feces would have originally attracted the flies, which would then have laid eggs. However, as this is not a species that is normally attracted to moving subjects, he postulated that the child must have been very still or perhaps unconscious by the time the flies laid their eggs. The physician suggested that the child would have passed out after about 24 hours of exposure, giving an estimate of time of abandonment at around 48 hours before discovery. This finding was used in the conviction of the mother.

This case illustrates the fact that it is extremely important for the forensic entomologist to be present at the scene, or at least to be made aware of the exact location from which the insects were collected. The fact that the diaper region, covered in clothing, was colonized before the much more accessible facial orifices would have suggested to the entomologist that colonization had occurred in life, as long as the entomologist collected the evidence himself or the entomologist was made aware of exactly where each exhibit was collected.

In many cases, however, colonization patterns may appear to be the same as that seen in normal colonization occurring after death. In a case in a city in British Columbia, an elderly man was found unconscious with severe head injuries. His face, mouth, and the head injuries were heavily colonized by third-instar blow fly maggots. He later succumbed to his injuries and died in a hospital. The sites of maggot colonization—the facial orifices and the head wounds—were the same as would be expected had he died immediately of his wounds; therefore, had he been found after death and the entomologist estimated the time of colonization, the estimate probably would have indicated the time of injury, not the time of death.

Although the idea of maggots feeding on live people is rather disgusting it can be useful in a forensic setting, as it allows an entomologist to estimate the length of time that has passed since the person was wounded or last received medical attention. In these cases, the victim is alive, so time of death is not the issue; rather, the length of time of neglect is the main concern. The temperature to which the insects have been exposed is known, as the person is alive, so the age of the maggots can be quite precisely estimated. The maggot age will indicate the minimum length of time since the person was injured or the length of time that the person has been neglected.

The majority of people who are colonized by maggots are those who are incapable or unwilling to look after themselves. This first category usually means the very young, the very old, or the temporarily or permanently incapacitated—people who rely on a caregiver for basic hygiene and care. In these situations, dirty diapers and bed sores are often attractive to insects. If a child or elderly person has not been receiving adequate care then insects may colonize. In many cases, it is can be difficult to prove neglect, but consider the case when maggots are found, for example, in a bed sore and the caregiver claims to have changed the bandage every day. The presence of six-day-old maggots clearly proves that in actuality the patient had not had a bandage change for more than six days, clearly and scientifically proving neglect and abuse. As most people, including jury members, feel strong revulsion at the thought of maggots feeding on a living person, forensic entomology becomes extremely probative evidence in court.

The second category of people with myiasis usually involves people such as alcoholics or drug users who, due to their intoxication, are unable to care for themselves or no longer care about personal hygiene. In these cases, myiasis relates not only to a lack of hygiene or attention to wounds but also sometimes directly to drug use. Many drugs are extremely damaging, not just psychologically but also physically. Cocaine is extremely corrosive; if it is snorted up the nostrils, after a time the cocaine begins to destroy the delicate tissue between the nostrils. This is just soft tissue so it is eventually eroded away until the nasal septum is destroyed and the person ends up with a single open area. It is not uncommon for this area to be colonized by maggots as the tissue dies. Some drugs taken orally also destroy mouth and gum tissue, and these areas can also be colonized in life.

A problem with dealing with a living victim is that the person or animal may be mobile; therefore, the non-feeding third-instar maggots that leave the food source could be dropped anywhere and may not be recovered. If only the person or animal is searched, then this could easily lead to severely underestimating the length of time of neglect. A person may have had an infested wound for some time, but because the insects will leave the host after a few days the insects found on the person would indicate a length of time of neglect of only perhaps seven days, whereas in reality the person has had an infested bed sore for weeks or more. It is therefore important for investigators to search bedding and clothing for later stage insects, just as would be necessary in the case of a dead victim. If the victim is fairly mobile and moves around a lot, then any areas where the person might have been should be searched (e.g., armchair that the victim sat in to watch television).

When a victim dies and the body decomposes, it only remains attractive to blow flies for a short period of time. By the time the first flies have completed their development on the body, the rest of the remains are no longer attractive to further blow fly colonization. In a living victim, however, successive generations of blow flies could colonize the tissue, again indicating that only a minimum time of death could be estimated by the insect activity.

If the victim is colonized during life but subsequently dies prior to discovery, the oldest maggots on the remains will indicate a date of colonization several days earlier than the actual death. Great care must be taken to consider the site of colonization, as this could indicate whether it was likely that the victim was colonized prior to death. As well, some insects will only colonize living victims but will survive if the person subsequently dies. If such species are recovered it clearly proves that the person was colonized in life.

Although the presence of fly larvae on a living person is repugnant to most people, the use of **maggot debridement therapy (MDT)** has had a long and successful history. Many species of blow fly feed exclusively on necrotic tissue, and medical practitioners discovered centuries ago that they could be used to cleanse wounds. Anecdotal reports of such use date back centuries, but it was during World War I when the American surgeon, Dr. William Baer observed it in action. During the trench warfare of World War I infection was rife and even the smallest wound could result in infection and death. The conditions of trench warfare did not permit even the slightest semblance of hygiene, and infected wounds often resulted in the amputation of a limb. Many soldiers subsequently died after such surgery.

In that sort of warfare, it was not uncommon for soldiers to be injured but caught in no-man's land, where it was impossible for their fellow soldiers to rescue them. As boundary lines shifted frequently, it was often possible that injured men could be recovered a few days later. In such cases, when an injured soldier had lain out for several days and was brought back into the army hospital area, it was noted that their wounds were often heavily maggot infested. This was, of course treated with a great deal of medical disgust and the maggots were removed, to reveal healthy, well granulated, pink tissue underneath. The act of removal often reinfected the wound and the soldier frequently succumbed. Dr. Baer took close notice of this and ordered that men brought into his area with such maggot infestations were to be kept comfortable, but their wound and its maggots were to be left alone. These were the men who recovered and walked home with all their limbs intact. Although this became accepted during war time, most surgeons did not feel that such an approach could be applied to modern, non-warfare medicine. Dr. Baer did not agree and brought maggot debridement therapy back to the United States, where he used it to treat thousands of children with osteomyelitis, a serious deep bone infection that invariably required amputation of a limb for the child to survive. Even today, it is extremely difficult to treat. Dr. Baer developed a method of attaching a cage of maggots over the affected area. The maggots cleaned the wound, and when they reached the wandering third stage they migrated out of the wound into the bandage, which was removed, incinerated, and replaced until the wound was clean. Many thousands of children owed their limbs and their lives to the pioneering work of Dr. Baer. A major drawback of this therapy was that back then there was no way to sterilize the maggots; as they went deep into a wound to clean out every small channel of infection, they could also carry bacteria into the wounds, resulting in serious infection in some cases.

Eventually the treatment fell by the wayside as antibiotics were discovered. As we all know, though, the overuse and misuse of antibiotics have led to widespread growth in bacterial resistance to antibiotics, and MDT experienced a major comeback in the 1980s, led by Dr. Ronald Sherman. Dr. Sherman has pioneered the use of MDT in the modern medical world, not only as a medical treatment but also as a medical treatment that can be used in modern, highly hygienic hospitals. In many cases, it is the hospital staff, not the patients, who are unnerved by the therapy. Dr. Sherman has shown that not only do the maggots remove the necrotic tissue and pus but they also secrete antibiotics and allantoin, which is so good at healing damaged tissue that it has been synthesized and is frequently found in hand creams. The actions of maggots inside a wound also stimulate the body to produce natural granulation. The wound of a healthy person heals rapidly due to new tissue formation, a process called *granulation*. If a person is immunocompromised then granulation often does not occur. A person with extensive bed sores, for example, may be unable to heal naturally. The actions of the maggot not only remove dead tissue but also seem to jump-start the immune system into responding by granulation. People who think about this for any length of time begin to realize that when maggots are living in a wound all of their bodily functions are occurring there, too. Specifically, the maggots are excreting into the wound, which sounds unhygienic, but actually these excretions contain ammonia, which alkalinizes the wound. Most wound bacteria prefer an acidic environment; by alkalinizing the wound the insects make it inhospitable for bacteria, further reducing the potential for infection. Today, MDT is commonly used worldwide and most modern hospitals will provide the therapy, although often they do not advertise this fact.

### *7.3.8 What Does a Lack of Insects on a Body Mean?*

It should now be clear that human remains or any other dead animal will be colonized by insects rapidly after death as long as certain conditions are met—primarily, carrion insects must be able to access the remains and the weather, season, and time of day must be conducive to insect activity. If a body is found that does not have insects on it, this could mean one of several things. It might mean that it is too early in the year for insects to have been able to colonize the remains, it is too cold for colonization, or the body has only been at the death scene for a very short period of time. In the last case, the body might have recently been dumped at the site but the person was killed and kept somewhere else where insects could not access the body beforehand, or the person may have been very recently killed. See Case Study 7.10 for an example.

**CASE STUDY 7.10: MS. KIRSTEN BLAISE LOBATO**

A man was found murdered several blocks from the Las Vegas strip on July 8, 2001, at about 10:00 p.m. He had suffered numerous injuries including stab and slash wounds. The original time since death was estimated medically as having occurred sometime between shortly before the body was discovered and no more than 12 hours prior to discovery. Eighteen-year-old Kirsten Blaise Lobato was identified as a possible suspect but had an accepted, unbreakable alibi that she was at her home three hours from Las Vegas from 11:30 that morning, effectively proving she could not have committed the murder. However, during her trial in 2002, the medical estimate of the time since death changed from the original estimate to between 10 to 18 hours before discovery of the man's body, which included about 4-1/2 hours outside the time of her accepted alibi. She was convicted of first-degree murder and sexual penetration of a dead body in 2002 but this was overturned due to multiple trial court errors in 2004, and she was retried in 2006. During the second trial, the medical estimate of the man's time of death was again that he could have died up to 18 hours prior to discovery of the body. This time, Ms. Lobato was convicted of voluntary manslaughter and sexual penetration of a dead body. She was sentenced to 13 to 35 years in prison. At no point in either trial was entomological evidence considered or even mentioned.

However, the entomological evidence, or in this case the lack of entomological evidence, is extremely important. Although the body was lying in a very accessible area, in a virtual blood bath at the height of summer, and offered multiple, attractive sites for blow fly egg laying, no eggs were present on the body when it was discovered. Blow fly eggs are laid in clumps (see Figures CS7.10.1 and CS7.10.2) and so are very visible. Close examination of photographs of the victim and crime scene indicate that, despite gaping bloody wounds, no eggs had been laid on the body. In late 2009, this case was brought to my attention and I examined the photographs and other evidence. The only explanation for the lack of eggs is that the victim must have died in the evening when no blow flies are active. That night, sunset occurred at 8:01 p.m., with civil twilight (when everyone driving must have their headlights on) occurring at 8:31 p.m. and nautical twilight (full dark) occurring at 9:08 p.m. Therefore, I concluded that, to a reasonable scientific certainty, the victim must have died after sunset and probably after nautical twilight. I also stated that the body could not have been at the crime scene during the day of July 8 without acquiring insect eggs. The expertise of a forensic pathologist also corroborated this time frame.

## 7.4 The Use of Insects in Investigating Wildlife or Pet Animal Crimes

Although forensic entomology is most commonly used in human homicide investigations, the insects we study live on dead meat and they do not care what type of animal that meat used to be. Hence, forensic entomology can be just as valuable in wildlife crime as it can be in human crime, and sometimes can be even more useful. Just as in a human homicide, it can be used to estimate when the animal died, whether it was moved or disturbed after death, the location of wounds, whether the animal was poisoned, and whether it was abused. The illegal killing of wildlife for

***Figure CS7.10.1*** Blow flies (Diptera: Calliphoridae) laying eggs inside the mouth of a pig carcass. Eggs can be seen at the edges of the mouth (arrow). These eggs were laid within less than 5 minutes of death.

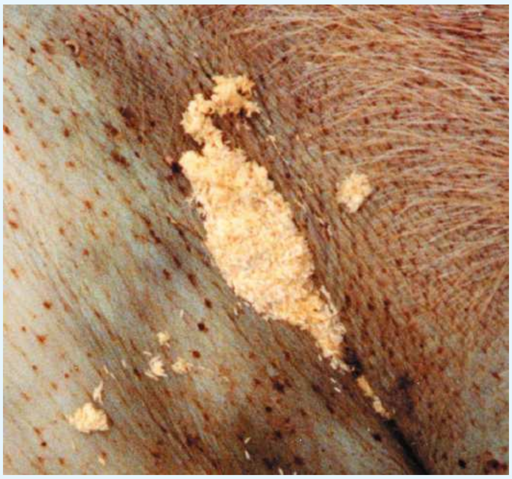

***Figure CS7.10.2*** Large clump of blow fly eggs (Diptera: Calliphoridae) on pig carcass. Mass is approximately 4 cm long. Eggs should be collected from central region and observed until hatched.

A habeas corpus petition in 2010 brought forward 21 grounds of new evidence, with the forensic entomology evidence being ground 1. This was denied in 2011. As of Spring 2013, Ms. Lobato's appeal is pending in the Nevada Supreme Court. Ms. Lobato remains in prison.

the wildlife trade is a major crime worldwide, and the illegal trade in animals and animal parts is a worldwide concern. Forensic entomology has been shown to also be very valuable in animal cruelty cases.

### *7.4.1 Estimating Minimum Elapsed Time Since Death in an Animal Crime*

Estimating a minimum elapsed time since death in an animal utilizes exactly the same techniques as described for homicide (see Case Study 7.11). Developing an accurate estimate of minimum elapsed time since death is valuable in making or breaking an alibi and understanding the timeline prior to death just as it is in humans, but in animal investigations it can go one step further. For many species of animals, it is legal to kill them within a certain time frame (i.e., hunting season) but illegal to kill them at any other time. Hunting laws can specify not only the overall time frame but also the time of day, the area, and the age and gender of the animal allowed to be legally taken. This means that estimating an elapsed time since death can be useful in animal cases under certain circumstances. If remains are found years after death, entomological evidence may indicate a particular season of death, such as spring, but would probably only suggest that death occurred more than a year ago; the actual year would be difficult to determine. This may not be of much value in a human death investigation, but in this case, if the species is not legally allowed to be hunted in the spring, then the insects have at least shown that this is a wildlife crime. Also, there can be a very short time frame between when it is illegal to kill an animal and when it is legal. If a game warden were to check a kill on the morning of the opening of the season for that species and suspects that the person jumped the gun and shot the animal the day before the season began, insect evidence may be used to prove whether the animal died that day (legally) or the day before (illegally).

In animal cruelty cases, estimating time of death can be valuable in working out if an animal was left untended for a period of time, such as when an owner finds his dog dead after leaving it at a boarding kennel for a week. The kennel owner says, "She must have just died, as she was fine when I fed her this morning." Insects on the remains would be able to determine the truth of such a statement. It can also be

**CASE STUDY 7.11: THE ILLEGAL KILLING OF BEAR CUBS**

At a rural garbage dump in the Canadian Prairies, three adult female black bears were killed and disemboweled, and their gallbladders were removed, meaning that the animals had been killed for profit, as bear galls have a very high value in traditional Chinese medicine. The killed bears had twin and triplet cubs, which were left orphaned at the garbage dump. Two of those tiny cubs were later found killed, disemboweled so their minute gallbladders could be removed. At this young age, their gallbladders had no commercial value. Fly eggs collected from the cubs indicated that death had occurred a matter of hours prior to discovery, and this information was used in the conviction of two men. They were convicted of two counts of poaching under the Provincial Wildlife Act of Manitoba and were sentenced to six months in prison (three months per cub). The maximum they could have received was six months per cub. The six months was appealed down to three months, but they did serve jail time, which was precedent setting for Canada for future cases. In his summing up, the judge considered the entomological evidence to be the "most compelling."

valuable in animal hoarding situations, where people take on many more animals than they can look after and some die. The estimated time of death of a number of animals in such a situation could be used when assessing the mental state of the owner.

### 7.4.2 Determining Whether the Carcass Has Been Moved or Disturbed

Although relocating a human body is not uncommon in homicide cases, it is extremely common in wildlife crime, as the animal is usually killed because a part of it is wanted, such as the horns, cape, head, hide, paws, or galls. Species differences in the insects at the scene compared with the carcass can be used just as in human cases, but many wild animals also carry parasitic insects and other arthropods in their hides such as ticks, mites, fleas, and lice. If the hide is removed, then these insects go with it. In one case, an offender killed a bear in the northeastern United States, skinned it, took it back to his home state, and claimed he had killed it legally there. Game wardens were suspicious; they confiscated the hide and invited an entomologist to examine it. Ticks were found that were indigenous to the kill site but not to the offender's home site and he was convicted of an illegal take. A carcass may also be disturbed. Some wildlife criminals will kill anything they can, remove the horns and cape, and bury them, in order to return at the end of the year to collect the beast, which they can claim on their tag as a legal take.

### 7.4.3 Locating Wounds in Wildlife

Locating a wound in a dead animal can be just as valuable as locating it in a human. When decomposed remains are found it might be assumed that the animal has died of natural causes but maggot activity would be an excellent clue as to the whereabouts of a wound. This can be extremely valuable for a game warden. When a human body is found, immediately an enormous process begins, with crime scene investigators, detectives, coroners or medical examiners, forensic pathologists and a host of other specialists involved. The remains are moved from the crime scene to the relatively pristine confines of the morgue, where an autopsy is performed by a forensic pathologist. It is not like that in wildlife crime, unfortunately. In most situations, a single game warden patrols a vast area. If animal remains are found or reported, it is often the job of that single warden to recover the evidence. Although some wildlife forensic laboratories do exist and are used to perform forensic analyses, in reality it is difficult or impossible for the game warden to collect and bring to the lab the entire rotting carcass of a grizzly bear or bull moose. Therefore, much of the forensic examination and almost all of the evidence collection must be done at the scene by the warden. Locating a wound and the projectile that caused it is paramount, and clues such as maggot masses that might indicate the presence and location of a wound are priceless.

### 7.4.4 Determining the Identity of Poisons in Wildlife

Unlike humans, animals do not take drugs deliberately, but they can be poisoned. This is often seen when poisoned carcasses are used as bait to get rid of predators such as wolves or coyotes that may be killing cattle or sheep. Not only is this practice illegal but it is also extremely dangerous, as the toxins kill not only the intended targets but anything else that may feed on the carcass such as raptors, dogs, and rodents. Many of the poisons used are so toxic that when these animals die and are fed on by other scavengers, these animals also die, creating identifiable rings of death for quite a distance from the original site. In fact, game wardens who do not recognize the ring of death and handle the carcasses without protection can also be poisoned through dermal absorption. Insects can be used to identify the poisons used just as they are used as toxicological specimens in human cases.

### *7.4.5 The Use of Insects in Establishing Abuse or Neglect in Animals*

Myiasis is much more common in animals than in humans. In wildlife, it can be used to estimate when the animal was injured and in a pet animal it can be also used to estimate the length of time of neglect. In one wildlife case, a person was hunting deer from a blind, but a mountain lion was prowling nearby, scaring off the deer. The person shot the lion but was a bad shot and only succeeded in wounding the animal. Not only was it illegal to shoot the lion, but injuring an animal makes it very dangerous as it is unable to hunt for its usual prey. A few days later, game wardens shot the animal. Maggots in the original wound were used to age the wound and to link the offender to the deer blind at the correct time frame, and he was convicted. In pet cases, it is common for an owner to claim that the animal was "just fine this morning and the wound must have just happened." The age of the insects can show whether it is possible that the wound is recent or much older. In the case of pet animals, it is particularly important to examine bedding and any areas where the animal sleeps to locate the insect evidence that may have already left the body.

## 7.5 Challenges to Forensic Entomology

As with any science, there are many things that impact the application of forensic entomology. Careful collection of entomological and environmental evidence as well as the upsurge in research in this area may ameliorate the effect of most of these issues.

### *7.5.1 Temperature*

Temperature is one of the most important factors that impact insect development, but in an investigation the actual temperature of the scene and that to which the insects have been exposed is unknown. The temperature can be estimated and extrapolated from a relevant weather station in concert with data loggers placed at the scene. Both macro- and microclimatic factors must be taken into account. The use of a data logger at the crime scene will indicate whether the data collected at the weather station is valid for the crime scene and whether the scene is, in general, warmer or cooler than that recorded at the weather station. A statistical analysis will allow the entomologist to deduce the scene temperatures based on a comparison of the temperature data at the scene and weather station.

### *7.5.2 Season*

Insects are seasonal, so forensic entomology is of value only in the spring, summer, and fall in temperate climates, although it is equally valuable all year round in tropical and subtropical regions (see Case Study 7.12). When recent remains are found in winter in temperate regions, there is little an entomologist can do. In some situations, though, the presence of a cold season may be of value in setting boundaries; for example, if remains are found in winter and clearly indicate the presence of insect activity, then death must have occurred prior to onset of the cold season.

**CASE STUDY 7.12: EFFECTS OF SEASON**

The highly scavenged partial remains of a victim were discovered with almost no insect evidence associated, except for some empty puparia of a common blow fly species. The remains were found in early spring, when it was not yet warm enough for insect activity to begin, so the insects could not have proceeded from egg to adult during the spring, as indicated by the empty puparia. Therefore, the meager insect evidence indicated that the victim had died the previous fall. In fact, the victim had died early enough in the fall for development of the blow flies to be completed, indicating the time since death.

### *7.5.3 Exclusion of Insects*

Insects may be excluded from the body by several means; an example is discussed in Case Study 7.13. The body may have been frozen after death. If this occurred naturally, during a winter season, then insects will colonize the remains when they thaw in spring. However, if the remains are artificially frozen in a freezer, insects will be excluded until the remains are removed from the freezer and allowed to defrost. Insects would still colonize the remains, and time since thawing could be determined. Burial can affect insect colonization, but few homicide victims are buried deeply

**CASE STUDY 7.13: EXCLUSION OF INSECTS**

A human body part was found inside a garbage bag with tie strings to tighten the bag. Maggots were found on the dismembered part, leading to a time of dismemberment. In most cases, the wrappings themselves are not breached, but the insects are able to move between the wrappings. The insects may have been delayed in reaching the remains, but their tenure on the body could still be determined, although the delay is difficult to calculate without completely recreating the scenario. In a case in Hawaii, Dr. Lee Goff recreated the case of a woman who was murdered then wrapped in two layers of blankets. He used a wrapped pig carcass to simulate the scenario and determined a delay of 2.5 days before insects accessed the body. This, together with the estimate of the insect's tenure on the body, resulted in a minimum postmortem estimate of 13 days. The victim had last been seen alive 14 days prior to discovery. Many victims are killed and left inside a house. This, too, can delay colonization. In experiments in Alberta, three freshly killed pig carcasses were placed inside a residential home (abandoned!) in different rooms and allowed to decompose for several weeks (Figure CS7.13.1). All carcasses were colonized but there was a delay of approximately five days before they reached the carcasses, whereas control carcasses placed outside were colonized immediately. The delay was caused by a number of factors and underscores the reason why an entomologist can usually only provide an estimate of the minimum elapsed time since death.

***Figure CS7.13.1*** Pig carcass.

enough to discourage all insects. Wrapping a body can limit or delay insect activity, but it rarely completely impedes insects. Several cases of bodies being wrapped in plastic or other materials or locked inside boxes, bags, or cases have been documented in which the insects were able to penetrate the wrappings and colonize the body.

## Chapter Summary

Forensic entomology is an excellent tool in a death investigation. It is the primary method for estimating elapsed time since death in the later postmortem interval and can be valuable for a year or more after death. It can also be used to determine other factors about the death.

## 7.6 Review Material: Key Concepts and Questions

### 7.6.1 Key Terms and Concepts

Bioaccumulate
Blow flies
Carrion
Entomology
Entomotoxicology
First instar
Frass
Maggot debridement therapy (MDT)
Myiasis
Puparial
Second instar
Successional colonization
Third instar

### 7.6.2 Review Questions

1. What is it about insect development that allows insects to be used to estimate elapsed time since death?
2. What is it about insect succession that allows insects to be used to estimate elapsed time since death?
3. When are blow fly eggs of most value?
4. What information is required to estimate elapsed time since death using maggot evidence?
5. What information is required to estimate elapsed time since death using insect succession?
6. How can insects be used as toxicological specimens?
7. How can insects be used to indicate wound sites?
8. Discuss three uses for insect evidence in wildlife crimes

## 7.7 References and Further Reading

### 7.7.1 Books

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### 7.7.2 Journal Articles

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Tomberlin, J. K., R. Mohr, M. E. Benbow, A. M. Tarone, and S. L. VanLaerhoven. "A Roadmap for Bridging Basic and Applied Research in Forensic Entomology." *Annual Review of Entomology* 56 (2011): 401–421.

### 7.7.3 Websites

http://medent.usyd.edu.au/projects/maggott.htm
www.aafs.org
www.csfs.ca
www.eafe.org
www.forensic.to
www.forensic-entomology.com
www.nafea.net

# Section III Summary

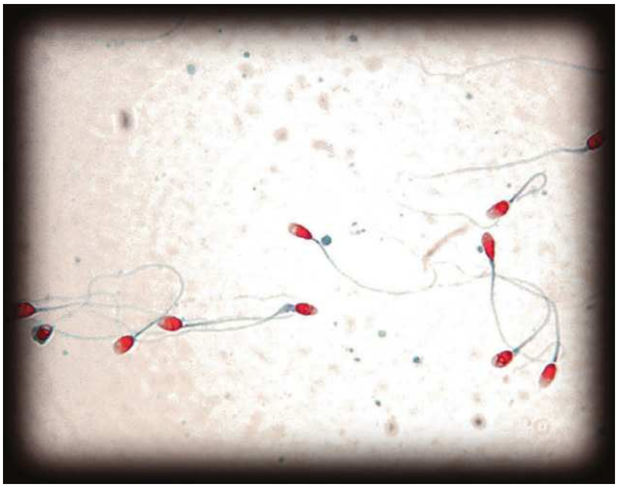
Forensic science cases often involve a death, as the central concern for a homicide case or related to a larger scenario. Currently there is no single death investigation system in the United States, but there are common elements. The three forensic disciplines that are most frequently involved in death investigations are forensic pathologists, forensic anthropologists, and forensic entomologists. These practitioners work in concert with crime scene analysts and other investigative personnel to determine the likely cause, manner, and mechanism of a death. Once this determination is made, it is up to the justice system to determine the next steps. In the next section, we will learn about forensic biology, which is related to and integrated with the topics we have discussed in this chapter.

## Integrative Questions

1. A partially decomposed body is found in the woods. There is no sign of foul play but no obvious indications of the cause of death such as weapons nearby. Describe which forensic practitioners would likely be involved in the death investigation. Which practitioner would you expect to be the final authority in such cases?
2. In the previous scenario, assume that it was discovered that the victim was uninjured and did not have any obvious findings of a disease. However, the toxicology report (discussed in Chapter 10) showed fatal levels of a pain reliever in the remaining tissues. What can be determined (and not determined) regarding the cause, manner, and mechanism of death?
3. Suppose that in the above scenario the body was not discovered until the remains were completely skeletonized. Assuming that it is not possible to test bones for drugs, can you think of any way that drugs might be found indirectly?
4. Consider the statement, “The biggest difference between archaeology and crime scene analysis is time.” What do you think this means? Do you agree? Use examples in your explanation.

# SECTION IV

# Forensic Biology



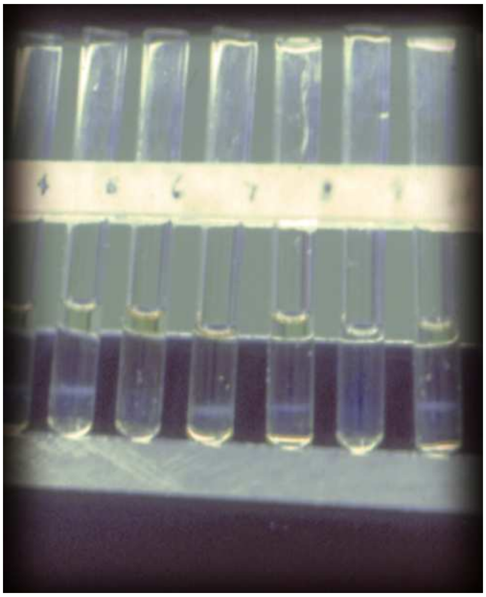
## Section Overview

We take it for granted that we can identify a red stain as blood, but until the early 20th century, even that simple task was a challenge. As the century evolved, the genetics that underlie blood types became a forensic tool, as did the ability to determine the genetic types of other proteins in the blood. Finally, at the end of the last century, the ability to type DNA and link it to a person emerged as one of the fundamental tools of identification. Blood is not the only body fluid of forensic interest, and as with blood, there are two challenges—first to identify a stain as coming from a particular body fluid and, second, to use genetic typing methods to link a stain to a person to the extent possible. We will discuss this in the first chapter of this section.

Although the value of DNA in criminal investigations is understood, the impact of developing DNA typing on forensic science is perhaps not as well understood. DNA typing results in a profile that can be linked to an individual with an accompanying number such as one in a trillion. Given that the population of the Earth is less than 10 billion, this number provides important data and context for evaluating the value of a DNA match. We do not see this approach in fingerprint analysis, the other method of individual identification. This has not gone unnoticed, and it is likely that as forensic science evolves the concept of probabilities associated with a result will become more important and expected. The story of DNA thus provides a unique window into the modern development of forensic science. This topic is the subject of the second chapter of this section.

# 8

# Identification of Blood and Body Fluids



## Chapter Overview

Large blood stains are easy to see, but not all crimes involve obvious stains and not all crimes involve blood alone. Other body fluids of forensic interest include saliva (oral fluid) and semen (seminal fluid). All are potential sources of DNA evidence, but they have to be identified as important before any analysis can take place. Laboratory methods available today enable forensic scientists to detect and identify extremely small quantities of body fluids. Once stains are located, samples can be collected and comparative DNA analysis may then be used to unequivocally eliminate an individual as a possible source of the fluids or attribute the origin to a particular individual with practical certainty.

# Chapter 8
# Identification of Blood and Body Fluids*

*Andrew Greenfield, Monica M. Sloan, and Robert P. Spaulding*

## Chapter Outline



* This chapter is based in part on Chapter 14, "The Identification and Characterization of Blood and Bloodstains," by Robert P. Spaulding, and Chapter 15, "Identification of Biological Fluids," by Andrew Greenfield and Monica M. Sloan, as published in the third edition of this text.

**SIDEBAR 8.1. CAREER PREPARATION AND EXPECTATIONS**

Forensic serology is no longer a commonly recognized discipline due to the advent of DNA typing methods. Most of the presumptive tests described in this chapter are performed by DNA analysts or by trace evidence analysts. You will find more information about career preparation for those fields in those chapters.

## 8.1 Forensic Serology

Technologies such as DNA analysis have captured our attention for both the uniqueness involved and the certainty with which an individual may be identified. However, DNA is a relative newcomer to forensic science, not much more than 30 years old. What preceded DNA as a means of analysis of blood and body fluids? The discipline called forensic **serology**. A study of serology involves the examination and analysis of body fluids and, among those fluids, blood. In the medical setting, blood is analyzed to assess one's state of health. Serologists type blood into groups in systems such as ABO and Rh. For example, if your blood type is A+ (a common type), this means that your red blood cells are type A and that your Rh type is +. These notations refer to the presence or absence of substances in your blood that can react with antibodies. In the forensic realm, blood might be analyzed to determine its source at a crime scene or on an item of evidence. The difference doesn't end here. A clinical serologist typically deals with samples that are fresh, normally liquid, and usually recently acquired from a source individual. Forensic serology deals not only with a variety of body fluids (blood, saliva, semen, and urine) but also, and more frequently, with samples that are in stain form and often degraded or deteriorated, making successful analysis more difficult. The reliability and discriminatory power of DNA analysis has led to the reanalysis of a number of cases in which the innocence of a convicted defendant has been established and the individual released. The superior power of DNA in individualization has been able to greatly extend the biochemical information provided by serology. This is not to say that the original serological work was wrong or performed with any fraudulent purpose but simply that employing DNA can provide more specific information, far exceeding that of serology. In situations such as these, the evaluation of the original serological data is made easier with a reference such as this text. From the foregoing, it should be evident that knowledge of serology or at least an availability of information on the subject is important to thorough forensic study. It is the intent of this text to review and discuss the more commonly used techniques of forensic serology regarding blood, provide sources of information, and present newer information. (For a discussion of career preparation for this field, see Sidebar 8.1.)

## 8.2 Blood

Identification of a stain as blood is one of the most important preliminary tests performed on physical evidence and one that DNA protocols have not replaced. Because of the time, cost, and complexity of DNA typing, it is impractical to test every stain that appears to be blood. This is where **screening** or **presumptive testing** is most important. Typically, the flow of analysis of a stain suspected to be blood moves from more general and less specific testing to DNA typing, which under the best circumstances can match a stain to an individual with reasonable scientific certainty. The analysis begins with a careful visual examination of the item of evidence to locate any stains or material visibly characteristic of blood. Any stains that look promising are then tested using a screening test; we will discuss the most common ones shortly. If the test is positive, then the species of origin of the stain may be tested but this is not always the case. We will see why in the next chapter. Finally, the blood is characterized using DNA, which will be discussed in detail in the next chapter.

### *8.2.1 What Is Blood?*

We discussed the composition of blood briefly in Chapter 4 in the context of bloodstain patterns. To review, blood is classified as an **extracellular fluid**, meaning it is found outside of cells in the body. We discussed some of the characteristics of blood in Chapter 4, and a few points are worth highlighting. Blood has many functions and is a complex mixture of organic and inorganic materials, including electrolytes such as sodium, proteins, and several different kinds of cells. The characteristic red of blood comes from the complex formed between **hemoglobin** in red blood cells (RBCs) and oxygen. The typical adult has a blood volume of around 4.5 to 6.5 liters (~1 to 2 gallons) depending on size and gender.

By spinning a blood sample in a centrifuge, it can be divided into a cellular component (approximately 45% of the total volume) and a non-cellular component called *plasma*, which makes up the remaining 55%. Plasma can be further subdivided into serum and fibrinogen, the material that forms clots. Serum, a clear straw yellow in color, carries electrolytes, with the sodium ion ($Na^+$) and the chloride ion ($Cl^-$) being the most concentrated. The bicarbonate ion ($HCO_3^-$) is also found in high concentrations and this is the form in which waste carbon dioxide ($CO_2$) is transported in the blood. Proteins (albumins and globulins) are also carried in the serum.

The cellular portion of blood can be divided into three types of cells: red blood cells (RBCs, or erythrocytes); white blood cells (WBCs, or leukocytes); and **platelets** (**thrombocytes**). RBCs, which transport oxygen and bicarbonate, are the most numerous and are unique in that they lose their nucleus before entering into the circulatory system. The substance that transports oxygen is hemoglobin. WBCs (several types exist) are the next most numerous and are active in fighting diseases. Platelets are needed for clot formation. DNA typing targets DNA found in the nuclei of cells and therefore requires white blood cells (or a cell with a nucleus).

### *8.2.2 Identification of Blood*

Identification of blood usually employs a presumptive test frequently followed by a **confirmatory test** to clearly establish the identification. A visual observation of the untested stain, coupled with positive chemical presumptive and confirmatory tests, then provides sound data to support the identification of blood. A presumptive test is one that, when positive, would lead the forensic examiner to strongly suspect blood is present in the tested sample. Notice this is not absolute; further testing is always required to confirm the results. When the results are negative, the test often helps to eliminate stains that need no further consideration. In the event of a positive test, when sufficient sample remains, further action to confirm the presence of blood is usually taken, since no single test is absolutely specific for blood.

Presumptive tests may be recognized as those that produce a visible color reaction or those that result in a release of light. Both types rely on the catalytic properties of blood to drive the reaction.

### *8.2.3 Catalytic Color Tests*

Catalytic tests employ the chemical **oxidation** of a **chromogenic substance** (one capable of generating a colored species) by an oxidizing agent catalyzed by the presence of blood or, more specifically, the hemoglobin or red pigment in the blood. Those tests that produce color reactions are usually carried out by first applying a solution of the chromogen to a sample of the suspected material/stain followed by addition of the oxidizing agent (often hydrogen peroxide in a 3% solution). The catalyst is actually the peroxidase-like activity of the heme group of hemoglobin present in the RBCs. A rapidly developing color, characteristic of the chromogen used, constitutes a positive test. Some methods employ the chromogen and the oxidant in a single solution. There is a potential disadvantage in this, however, as the order of addition of the specific reagents can be important. A non-blood sample capable of producing a color reaction will normally do so without the addition of the oxidizing agent so that when the color reagent is added first there is a reaction (without the addition of the oxidant). With a single solution, a reaction due to a non-blood material might be incorrectly interpreted. Twenty or more substances have been investigated over the years as chromogens; we will focus on the ones most commonly used today.

Because these tests are presumptive in nature, inevitably there are instances of **false positive results** (a positive result from a substance other than blood for example) and **false negative results** (a negative result even when blood is present). Misleading results usually can be attributed to chemical oxidants (often producing a reaction before application of the peroxide), plant materials (vegetable peroxidases are thermolabile and can be destroyed by heat), or materials of animal origin (to include human) which are not blood but may contain contaminating traces of blood. An analyst must always be cognizant of this possibility. The proper use of positive and negative controls is an important step in minimizing false positives and false negatives.

One method of applying the presumptive test involves sampling a questioned stain with a clean, moistened cotton swab and adding a drop of the color reagent solution followed by a similar amount of hydrogen peroxide ($H_2O_2$). With this procedure, the immediate development of the color typical of the particular reagent used indicates the presence of blood in the test sample. Alternatively, the evidence could be sampled by removal of a thread or fragment of dried material and testing it with the above reagents in a spot plate. Color development would then be observed in the spot plate as well. Immediate (within a few seconds) reading and recording of results is an important aspect of test result interpretation. A clearly negative result may appear positive several minutes after the test is completed due to a slow oxidation that often occurs in air. These tests are not usually affected by the age of the stain.

### *8.2.4 Benzidine (Adler Test)*

**Benzidine** has been used probably more extensively than any other single test for the presumptive identification of blood. The reaction (Figure 8.1), normally carried out in an ethanol/acetic acid solution, results in a characteristic blue to dark blue color. The blue, in turn, may eventually turn to a brown. Benzidine, however, is recognized as a carcinogen and is seldom used in forensic laboratories today. Other test reagents such as *o*-toluidine were largely abandoned for the same reason.

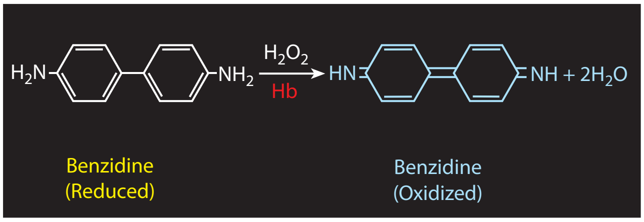



***Figure 8.1*** Benzidine oxidation.

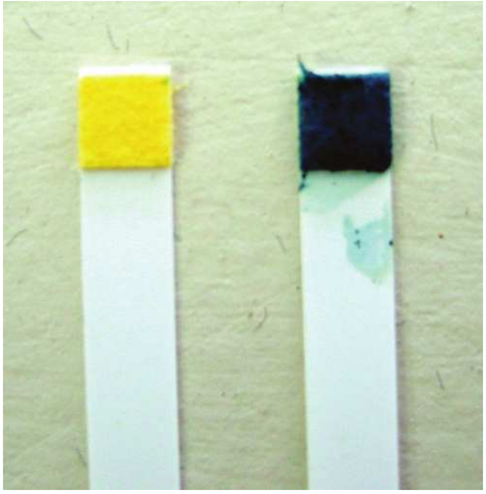


***Figure 8.2*** Hemastix® negative and positive reactions.

### *8.2.5 Tetramethylbenzidine and Hemastix®*

With the recognition of benzidine as a carcinogen, the search for replacement substances was under way. One compound studied and still used is the 3,3′,5,5′-tetramethyl derivative of benzidine. **Tetramethylbenzidine (TMB)** is used in an acid medium (acetic acid) when employed as a solution, and the resultant color is green to blue-green. The **Hemastix®** test has been adopted for field use by a number of laboratories, particularly at crime scenes when containers of solutions can be hazardous or, at best, inconvenient. The test itself consists of a plastic strip with a reagent-treated filter paper tab at one end. Testing a bloodstain may be accomplished by moistening a cotton swab with distilled water, sampling the stain, and touching the swab sample to the reagent tab on the strip. The reagent tab is originally yellow, and a normally immediate color change to green or blue–green indicates the presence of blood (Figure 8.2).

### *8.2.6 Phenolphthalein (Kastle–Meyer Test)*

A test procedure that is commonly used in many forensic laboratories today involves the simple acid–base indicator **phenolphthalein**. Phenolphthalein produces a bright pink color when used as above in testing suspected blood. The reagent consists of reduced phenolphthalein (phenolphthalin) in alkaline solution, which is oxidized by peroxide in the presence of hemoglobin in blood. The reaction shows phenolphthalin (which is colorless in alkaline solution) being oxidized to phenolphthalein (which is pink in an alkaline environment) (see Figures 8.3 and 8.4). As with any of the catalytic tests the result is read immediately, and a

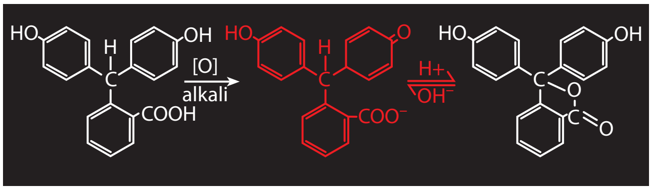



*Figure 8.3* Phenolphthalin oxidation. Phenolphthalin (left, colorless) is catalyzed to phenolphthalein (pink in alkaline solution, center), which is colorless in acid (right).

*Figure 8.4* Negative and positive phenolphthalein reactions.

positive result a minute or more after the test is performed is usually not considered reliable. False positives with phenolphthalein usually are not really positives, in that the reaction is often not the characteristic pink but usually some other color change.

### *8.2.7 Tests Using Chemiluminescence and Fluorescence*

Often, the presence of blood is suspected, based on witness information or because it would be expected in a particular location, but under normal lighting and viewing little is to be seen. A drag pattern across a floor that has been cleaned up or a washed spatter pattern on a wall might be typical examples. At this point the **luminol** and **fluorescein** tests may come into play. They involve spraying a chemical mixture on a suspected bloodstained area, usually *in situ*, and observing (sketching, photographing, etc.) the result, either in darkness or in reduced light with the aid of an **alternative light source (ALS)**. When luminol reacts with blood, light is produced that often enables the observer to determine the limits, shape, and some degree of detail in the original bloodstained area, often including an enhancement of blood patterns already present.

The presence of blood and patterns displayed by blood can provide information of value, and one should be alert to both. Further, the nature of these tests makes them potential sources of contamination of the blood. Thus, if the stain can be seen and collected, these tests probably should not be used. Because these tests do add material to the tested area, their use should be carefully considered, often as a last resort. These tests are of more value in locating and defining blood than in specifically identifying it.

Luminol and fluorescein each produce light but they do so in different ways. **Chemiluminescence** and fluorescence are two entirely different phenomena. Chemiluminescence is the process by which light is emitted as a product of a chemical reaction. No additional light is required for the reaction to take place. Luminol relies on this process. Fluorescence occurs when a chemical substance is exposed to a particular wavelength of light (usually short wavelengths, such as ultraviolet), and light energy is emitted at longer wavelengths. Light produced by fluorescein is a result of this irradiation, usually by light in the range of 425 to 485 nanometers.

Luminol reacts in a fashion similar to that of the color tests discussed above wherein luminol and an oxidizer are applied to a bloodstain. The catalytic activity of the heme group then accelerates the oxidation of the luminol, producing a blue-white to yellowish green light (depending on the reagent preparation) where blood is present. The forensic application of luminol at crime scenes involves spraying a mixture of luminol and a suitable oxidant in aqueous solution over the area thought to have traces of blood present. A resultant blue-white to yellow-green glow will indicate the presence of blood. Outlines and details are often visible for up to 30 seconds before additional spraying is required. Excessive sprayings will usually result in stain pattern diffusion. Luminol is one of the most sensitive of the presumptive tests and is capable of detecting traces of blood in parts-per-million concentrations. Interestingly, luminol can also react with blood that has been painted over, such as on walls.

Fluorescein is prepared for use much like phenolphthalein. Fluorescein is reduced in alkaline solution over zinc to fluorescin, which is then applied to the suspected bloodstained area. The catalytic activity of the heme then accelerates the oxidation by hydrogen peroxide of the fluorescin to fluorescein, which will fluoresce when treated with ultraviolet light. Fluorescein and luminol are similar in that they produce light to indicate the presence of blood; however, practical differences exist in the use of the two. Whereas an aqueous solution of the luminol reactants is simply sprayed on a surface bearing suspected bloodstain residues, a common fluorescein system includes a commercial thickener, which effectively causes the mixture to adhere to the surface and is thus more effective on vertical surfaces. Once the mixture is sprayed, visualization of fluorescence requires the use of an alternative light source, typically set at 450 nanometers.

### *8.2.8 Confirmatory Tests for Blood*

Once a stain has been tentatively identified as blood, the next step is frequently a confirmation test. In some cases, the analyst may proceed directly to DNA typing, knowing that only human DNA will be detected and typed using current methods. In cases where a more definitive identification of a stain as being blood is desired, confirmatory tests such as **crystal tests** (also called **microcrystal tests**) may be used. These tests target the non-protein heme group of hemoglobin, the oxygen-carrying protein of erythrocytes that belongs to a class of compounds called *porphyrins*. The heme structure contains an iron atom that is hexavalent, meaning it can interact with six different entities. Nitrogen atoms within the ring structure bind four of the iron coordination positions and one is bound to histidine nitrogen in the globin protein. In hemoglobin, the remaining coordination position is normally bound by water or, in oxygenated hemoglobin, oxygen. In dried bloodstains, these last two positions are used in the formation of crystals that are the basis for confirming the presence of blood.

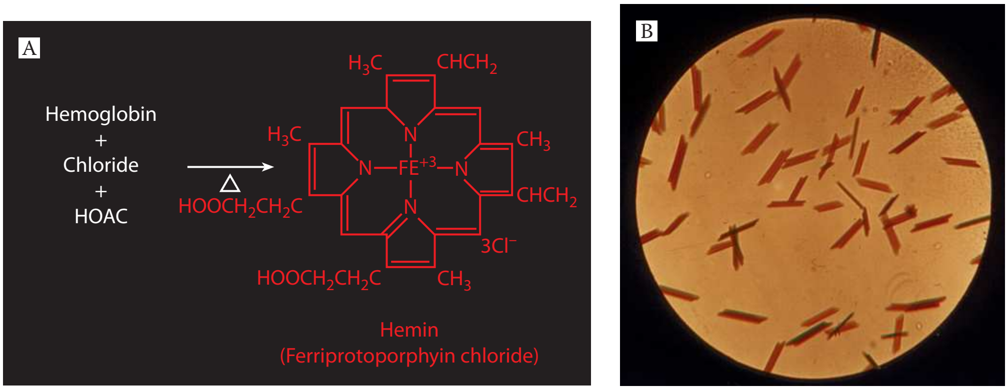



*Figure 8.5* (A) Teichmann reaction. (B) Teichmann crystals.

The two common crystal tests are the **Teichmann test** and the **Takayama test**. The Teichmann test consists of heating dried blood in the presence of glacial acetic acid and a halide (usually chloride) to form the **hematin** derivative (Figure 8.5A). The crystals (Figure 8.5B) formed are observed microscopically; they are usually rhombic in shape and brownish in color. The crystals are formed by placing a sample of suspected blood on a microscope slide and adding a small amount of chloride-containing glacial acetic acid followed by heating.

If heme is gently heated with pyridine under alkaline conditions in the presence of a reducing sugar such as glucose, crystals of pyridine ferroprotoporphyrin or hemochromogen (Figure 8.6A) are formed. The reaction was studied by Takayama (1912), who examined several mixtures and found best results with a reagent containing

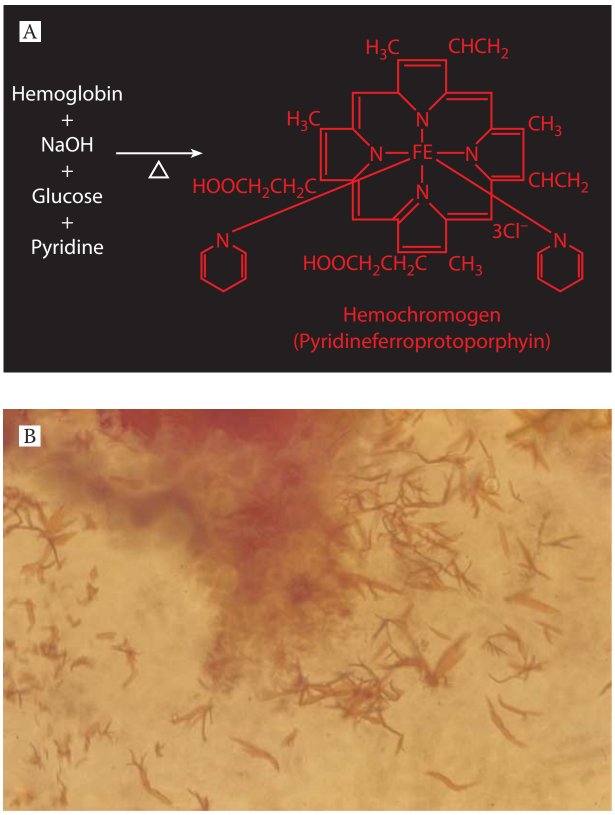



*Figure 8.6* (A) Takayama reaction. (B) Takayama crystals.

water, saturated glucose solution, sodium hydroxide (10%), and pyridine in a ratio of 2:1:1:1 by volume. The normal procedure is to place a small stain sample under a cover slip and allow the reagent to flow under and saturate the sample. After a brief heating period, the crystals are viewed microscopically (Figure 8.6B). A very small cover slip (2-mm square or smaller) allows the test to be carried out on a small stain quantity.

### *8.2.9 Species Origin Determination in Bloodstains*

Current methods of DNA typing target human DNA, so there is usually no need to identify what species a blood sample came from. Before DNA methods were widely used, it was often necessary to identify the species. Consider a crime scene in a kitchen where meat is prepared. Blood in a sink could come from a human victim but it also might have come from fresh steak. Serologists had to be sure that the blood was human before doing more testing, as the testing itself was not species specific. Most of the tests used are based on **immunological reactions** in which an **antigen (Ag)** reacts with an **antibody (Ab)** to produce a visible solid or precipitate. In this context, antibodies are proteins found in the serum portion of blood. A wide variety of tests is available to determine the species origin of an identified bloodstain, and most employ immunoprecipitation.

If a host animal (e.g., a rabbit) is inoculated with a serum protein (e.g., human), the immune system of the animal will normally recognize the protein as foreign and produce antibodies against it. Harvesting the antibodies provides an antiserum to the protein (antigen), and when a sample of the antiserum and the antigen are brought into contact a precipitin reaction normally occurs. The precipitate may form in a gel or in a solution, but its formation signals a reaction has occurred. This visible result is the basis of several species tests.

The ring **precipitin test** employs simple diffusion between two liquids in contact with one another in a test tube (see the photograph at the start of the chapter). The two liquids are the antiserum and an extract of the bloodstain in question. If the antiserum (antihuman) is placed in a small tube, and a portion of the bloodstain extract (human) is carefully layered over the denser antiserum, dissolved antigens and antibodies from the respective layers will begin to diffuse into the other layer. The result will be a fine line of precipitate at the interface of the two solutions. In the case where the bloodstain extract is not human, there should be no reaction. Occasionally, there will be more than one precipitin band, indicating different reacting components with different diffusion coefficients. A standard operating procedure would be to include necessary positive and negative controls with a questioned sample.

The Ouchterlony double diffusion test is carried out in a gel on a glass plate. A hot agar solution is plated on small glass plates or a Petri dish and allowed to cool, producing a gel layer usually 2 to 3 millimeters thick. Holes (wells) are punched in the gel layer at specified locations and the gel is removed. Commonly used patterns are a square of four wells, a rosette of six wells surrounding a center well, or two rows of parallel wells. When the antiserum and stain extracts (antigen) are prepared, the antiserum is placed in the central well and the different stain extracts in the surrounding wells. The system is then incubated at constant temperature (4, 18, or 37°C are commonly used). After a given period of time, the diffusion of the reactants through the gel results in the formation of immunoprecipitate lines in the gel between the wells (Figure 8.7). This precipitate is a stable antigen–antibody complex that has grown beyond the limits of its solubility.

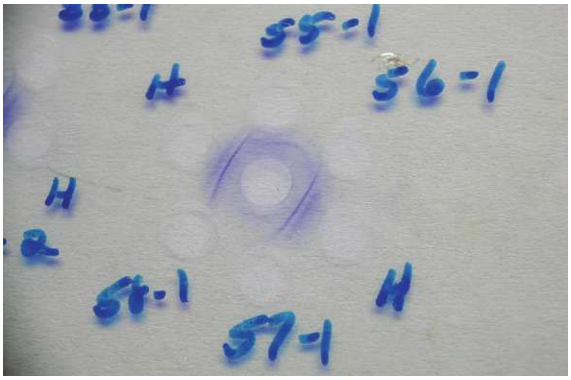



***Figure 8.7*** The Ouchterlony double diffusion test.

Antihuman serum from the center well forming an immunoprecipitate with a sample from one or more of the surrounding wells indicates the presence of human protein in the respective outer wells. The precipitate may be stained with a suitable protein stain. Although the point at which the immunoprecipitate forms is controlled by the diffusion coefficients of the reactants, its formation is dependent on the concentration of reactants and the identities of the reactants. When antigen and antibody are present in relatively equivalent amounts, the line grows in an arc between the two wells. Incubation at cooler temperatures is a slower process but has the advantage of producing sharper lines and sometimes additional precipitin lines, due to reduced solubility at lower temperatures.

### *8.2.10 Prelude to DNA: Genetic Markers*

Prior to DNA typing, blood was characterized by other tests, also broadly referred to as typing. Like DNA, these tests targeted inherited characteristics under hereditary control and are referred to generically as **genetic marker systems**. Some, such as the **ABO blood group** system (see Sidebar 8.2), are amenable to forensic

#### SIDEBAR 8.2. HISTORICAL NOTE: BLOOD TYPES AND KARL LANDSTEINER

Karl Landsteiner (1868–1943) was an Austrian physician who was the first to study and identify the ABO blood group at the turn of the 20th century. His research was not focused on forensic science, but on fatal reactions being observed with blood transfusions that were tried in the 1800s. These early attempts frequently caused the red blood cells of the recipient to clump together (agglutinate). Landsteiner noted that this reaction was not universal in that the blood of some individuals was compatible. These observations coupled with his research led to the identification of the ABO system, which was the first blood group system identified. Landsteiner also recognized that a person's blood group was inherited and thus would be useful in paternity cases. Landsteiner's discovery led to systematic typing for blood transfusions and saved untold thousands of lives. As a result, he was awarded the Nobel Prize in Medicine in 1930. Landsteiner eventually moved to New York and continued to work in the field of immunology, participating in the discovery of several more blood group systems, including the Rh system discussed briefly in this chapter.

**TABLE 8.1**
**ABO Blood Group Characteristics**

| Blood Group | Antigen Present | Specific Sugar | Antibody Present | Population Frequency |
|---|---|---|---|---|
| A | A | *N*-Acetylgalactose amine | Anti-B | 40% |
| B | B | D-Galactose | Anti-A | 10% |
| AB | A, B | D-Galactose and *N*-acetylgalactose amine | None | 5% |
| O | H | L-Fucose | Anti-A and anti-B | 45% |

settings, and types can be retrieved from stains, even old and degraded ones. Other systems that are easy to type in whole blood are not typable in stains. We will examine a few of the genetic marker systems used in forensic serology.

The first and best-known blood grouping system is the ABO system, discovered by Karl Landsteiner in 1900. The types A, B, O, and AB refer to the antigens (**agglutinogens**) on the surface of the red blood cells, which are glycoprotein substances and an integral part of the cell membrane. The corresponding antibodies (**agglutinins**) of the system—anti-A (α-A) and anti-B (α-B)—are present in the plasma. These characteristics are summarized in Table 8.1. A person of blood group A will have anti-B (α-B) antibody in his or her plasma, and if that plasma is mixed with group B cells the two are said to be homologous, with agglutination being the result. The characteristics of the person who is group O present a little different picture. There are no routinely occurring antibodies in humans for the red cell H antigens possessed by the group O person. However, certain seed extracts called *lectins* are capable of achieving agglutination with blood cells. One of the reasons for knowing blood types is for transfusions; if a person with type B blood is given type A blood, a fatal reaction can occur.

Forensic testing for the ABO system in dried bloodstains centers on identifying both the antigen and antibodies present. A variety of methods have been devised to accomplish both tasks. The **absorption elution** test involves the exposure of a portion (a cutting or thread) of the stain bearing the blood (and antigen) to absorb the homologous antibody. Unreacted antibody is then washed away and the absorbed antibody is eluted by warming and then mixed with a cell suspension to be identified. As an example, a group A stain exposed to anti-A (α-A), anti-B (α-B), and anti-H lectin (α-H lectin) antibodies in separate containers (tubes, wells, etc.) would absorb the anti-A and not the anti-B or anti-H antibodies. After allowing sufficient time for absorption, the unreacted antibodies (and lectin) would be washed away and gentle heating would be applied to release (elute) the absorbed anti-A. This anti-A antibody would be detected by the addition of group A cells, which would then agglutinate and be viewed microscopically. The other two containers would exhibit no reaction as no antibody or lectin was absorbed and then eluted to react with the B and O cells added.

The **Lattes crust test** focuses on the antibodies found in the stain and involves exposing three separate stain samples to dilute suspensions of A, B, and O cells (usually on glass microscope slides), allowing a suitable period of time for elution of the antibodies from the stain and agglutination of the cells. A positive result or agglutination on the slide with the B cells would indicate anti-B antibody in the stain and thus confirm the stain as blood group A. It is well known that some individuals secrete their ABO biochemical (antigenic) characteristics into body fluids such as saliva, semen, and vaginal fluid. Such individuals are called **secretors**, which represent approximately 80% of the general population. The remaining 20%

of the population are non-secretors. This finding was important forensically as it allowed blood group typing (ABO) to be conducted on evidence such as cigarette butts, using techniques similar to those just described.

### 8.2.11 Enzyme Markers

Between 1971 and the coming of age of DNA in the mid- to late 1980s, interest in polymorphic **enzyme systems** and their analysis was high. The result was a flourishing of technology designed to identify the different types of a host of enzymes, centering mainly on electrophoresis and isoelectric focusing (IEF) methods. This advancement in technology led to a greater ability to discriminate between individuals and evidentiary material and paved the way for the more advanced technologies of DNA analysis. Methods have been developed for numerous enzymes with regard to their use in individualizing bloodstains (Table 8.2), but space precludes a complete discussion of them. **Phosphoglucomutase (PGM)** has been chosen as a representative enzyme for discussion (see Case Study 8.1).

Although the development of techniques enabled a greater discriminatory capability, there was still the basic nature of the macromolecules to contend with. The basic structure of proteins and enzymes is complex, both in physical structure and chemical nature. While many of the systems mentioned above are sensitive to unfavorable environmental conditions, proteins and enzymes are much more susceptible to such antagonism. A change in the molecule's physical structure or the ability to perform its chemical task will often result in an inability to detect any phenotype in evidentiary stains. Thus, the results of heat and humidity become even more significant when dealing with these markers. A discussion of unfavorable environmental conditions often brings up the question of altered phenotypes being observed in the analysis of improperly stored evidentiary stains. In other words, would a PGM 1+1B become a PGM 2+2B? In fact, it may be shown that the result of subjecting evidence to unfavorable conditions is likely to be the loss of any detectable phenotypes rather than the introduction of new ones. A term one will find mentioned in connection with forensic enzyme assays is **polymorphism**. Polymorphism may be described as the occurrence in a population of two or more genetically determined alternative

**TABLE 8.2**
**Forensically Important Enzymes**

| Enzyme | Abbreviation | Common Phenotypes | Remarks |
|---|---|---|---|
| Adenosine deaminase | ADA | 1, 2, 2–1 | Rare variants exist (3–1, 4–1, 5–1, 6–1, 7–1) |
| Adenylate kinase | AK | 1, 2, 2–1 | Rare variants exist (3–1, 4–1, 5–1) |
| Carbonic anhydrase | CA II | 1, 2, 2–1 | Takes 4 to 6 years to reach adult levels |
| Erythrocyte acid phosphatase | EAP, ACP | A, B, BA, C, CA, CB | Stability of bands C > B > A |
| Esterase D | ESD | 1, 2, 2–1, 1–5, 2–5, 5 | Five allelic products observable with IEF |
| Glucose-6-phosphate dehydrogenase | G6PD | A, B, AB | Mainly polymorphic in blacks; AB normally |
| Glyoxalase | GLO I | 1, 2, 2–1 | In sperm and plasma |
| Peptidase A | PEP A | 1, 2, 2–1 | In plasma more than sperm |

## CASE STUDY 8.1: APPLICATION OF ABO

During the early morning hours of a June day in a northeastern community, the teenaged daughter of the headmaster of a prestigious girl's school was awakened in her own bed and carried downstairs and into the back yard, where she was sexually assaulted and forced to commit sodomy. She had limited vision without her glasses and was later unable to identify her attacker except to provide a general description. When released, she fled to wake her parents who immediately reported the incident to the police. The girl's injuries included a vaginal laceration, which bled profusely.

Shortly after the police were notified, an individual who fit the general description given by the girl was located walking on the street about five blocks from the scene. The individual explained that the blood-like stains around the fly area on his blue jeans came from a nosebleed suffered by his girlfriend's daughter earlier that day.

The blue jeans, the girl's nightgown, and liquid blood samples from all three individuals were subjected to forensic examination. Human blood was, indeed, identified on the nightgown and the blue jeans. ABO analysis of the blood samples disclosed that the girl, the suspect, and the blood on the pants and the nightgown were all of blood group A, while the girlfriend's daughter was group O. Additional analysis of the known samples disclosed the girl to be PGM 2–1, EAP BA, Hp 1; the suspect, PGM 1, EAP A, Hp 1; and the girlfriend's daughter, PGM 1, EAP B, Hp 2–1. The blood on the pants and nightgown was PGM 2–1, EAP BA, and Hp 1, indicating the young girl as a possible source but eliminating the others. All additional testing was inconclusive. No semen was identified on the evidence. The blood on the jeans could have come from the victim but not the suspect or his girlfriend's daughter.

The significance of these results becomes clearer when we look at the relative frequency of the victim's set of types in the population. The population frequencies for the victim's characteristics are ABO A, 40%; PGM 1, 35.9%; EAP A, 41.4%; and Hp 1, 16.5%. The combination of these frequencies ($0.40 \times 0.359 \times 0.414 \times 0.165$) gives us 0.0098; in other words, 0.98% of the population can be expected to have all the characteristics of the victim. Stated differently, there is roughly 1 chance in 100 that we can randomly select a person from the population of that town with that combination of phenotypes. Had this case been examined when PGM subtyping was available and the victim had been the most common subtype of PGM 1, the figure would have been 0.006 or 0.6%, or 1 chance in 167. The result for the least common PGM subtype would have been 0.0004 or 0.04%, or 1 chance in 2500. Although this may sound impressive, DNA typing methods, described in the next chapter, can yield numbers in the range of 1 in billions or even trillions.

phenotypes with frequencies greater than could be accounted for by mutation. That is, two or more alleles for the production of the enzyme exist in the population. If enough samples are analyzed, they will be observed.

Phosphoglucomutase is a phosphotransferase enzyme that catalyzes the reversible conversion of glucose-1-phosphate to glucose-6-phosphate, an essential reaction in carbohydrate metabolism in the body. It is found in many tissues of plants,

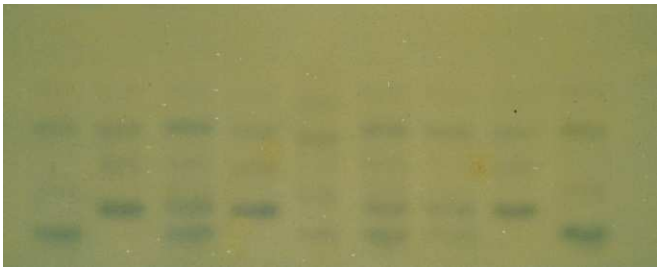


***Figure 8.8*** PGM phenotypes (electrophoresis). From left to right: PGM 1, PGM 2, PGM 2-1, PGM 2, PGM 1, PGM 2-1, PGM 2-1, PGM 2, PGM 1 (anode at top).

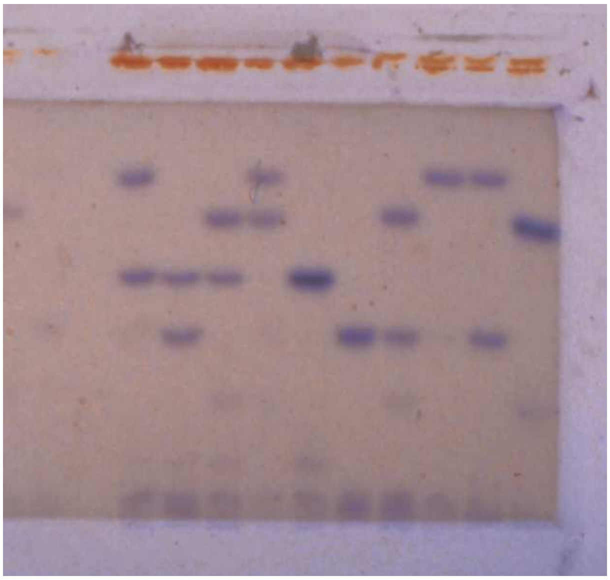


***Figure 8.9*** PGM phenotypes, (isoelectric focusing). From left to right: PGM 1+2+, PGM 1+1–, PGM 1+2–, PGM 2+2–, PGM 1+, PGM 1–, PGM 1–2–, PGM 2+, PGM 1–2+, PGM 2– (anode at top).

animals, and microorganisms. In humans the enzyme exists in significant concentrations in blood and semen and in small amounts in vaginal secretions and cervical mucus. It is known to be inhibited by heavy metals and fluoride, a significant point as blood samples taken by medical personnel may contain fluoride. When stored under cool dry conditions the enzyme survives well. It should always be the concern of the forensic investigator, however, to avoid exposing biological evidence to prolonged heat and humidity.

There are actually three genetic loci that control PGM polymorphism. Locus 1 is on chromosome 1, locus 3 is on chromosome 6, and locus 2 is on chromosome 4. Only polymorphism originating at locus 1 is considered forensically important. Initially, electrophoresis of forensic samples for PGM activity routinely detected three phenotypes: PGM 1, PGM 2, and PGM 2–1 (Figure 8.8). Subtypes have also been identified, widening the range of possibilities to PGM 1+, PGM 1–, PGM 1+1–, PGM 2+, PGM 2–, PGM 2+2–, PGM 2+1–, PGM 2+1+, PGM 2–1+, and PGM 2–1– (Figure 8.9). Each of these types is present in the population with a specific frequency, with some being more common than others. With this ability to place the subtypes of PGM in ten different population groups (usually expressed as percentages) instead of three, the enzyme presents the highest discrimination probability of any enzyme system commonly used in forensic serology.

## 8.3 Seminal Fluid

Next to blood, the body fluid most often seen in forensic cases is semen or seminal fluid. Semen is produced by post-pubescent males and ejaculated following sexual stimulation. It is a semifluid mixture of cells, amino acids, sugars, salts, ions, and other organic and inorganic materials elaborated as a heterogeneous gelatinous mass contributed by the seminal vesicles, the prostate gland, and Cowper's glands. Ejaculate volumes of human males range from 2 to 6 milliliters and typically contain between 100 and 150 million sperm cells per milliliter. Certain disease states, genetic conditions, excessive abuse of alcohol or drugs, prolonged exposure to certain chemicals, and elective surgery procedures may result in a drastically reduced sperm count or complete absence of sperm cells from semen.

### *8.3.1 Sperm Cells*

The principal cellular component of semen is the spermatozoa or sperm cell, a specialized, flagellated structure approximately 55 micrometers (μm) in length. The human sperm cell head is typically ovoid in shape with approximate dimensions of 4.5 μm in length, 2.5 μm in width, and 1.5 μm in thickness. The head contains the cell nucleus. The anterior portion of the head is capped with the acrosome. This structure is rich in enzymes to assist in penetrating the cell wall of the female egg during fertilization. A flagellated tail is attached to the head via a short midpiece and accounts for about 90% of the total length of a sperm cell. A common method of detecting semen is to stain the sperm cells to allow for visual detection using a microscope.

The condition of **azoospermia** (semen lacking spermatozoa) requires that other tests besides identification of the sperm be used. Crystal tests in which chemical components of semen such as spermine and choline could be detected were developed to assist with the identification of such samples. Characterization of enzymes in animal body fluids and tissues began in the 1920s, and by the mid-1930s a test was developed to test for **seminal acid phosphatase (SAP)**. Modifications of the test remain in widespread use today. By the 1970s, analysis of stains for protein components of seminal fluid was commonplace.

### *8.3.2 Acid Phosphatase*

**Acid phosphatases (APs)** are a class of enzymes that can catalyze the hydrolysis of certain organic phosphates. These enzymes are ubiquitous in nature and may be found in materials as diverse as mammalian liver and cauliflower stem juice. Seminal acid phosphatase (SAP) is a phosphatase found in human semen at uniquely high levels compared with other body fluids and plant tissues. In males, puberty stimulates the large-scale synthesis of SAP by secretory epithelial cells that line the prostate gland. SAP levels remain high until the age of about 40, after which they gradually decline. No correlation exists between the level of SAP and the number of sperm cells present in an ejaculate, and no variation has been found between males with normal sperm counts and those who are clinically infertile or who underwent vasectomies.

Over the years, many methods for the presumptive identification of semen have been devised. Only one, the test for SAP activity, has withstood the test of time and is now used for this purpose. It involves a reaction that generates a color by combining a substrate (here, something that will react with the phosphatase enzyme) with

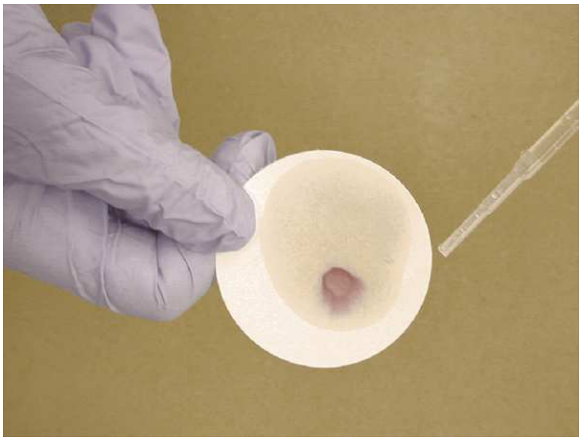


***Figure 8.10*** Test for SAP activity.

a color developer. In forensic laboratories, alpha-naphthyl phosphate is the preferred substrate and Brentamine Fast Blue B is used as the color developer. These two components are prepared separately in anhydrous sodium acetate and mixed to create a working solution or reagent that is sensitive enough to produce a positive result with semen diluted 500 times. This test is especially practical because it does not require that a suspected semen stain first be localized visually before applying it.

Application of the test is a very simple two-step procedure. Because SAP is readily soluble in aqueous media, a piece of absorbent paper (filter paper is ideal since it comes in a variety of sizes) or cotton swab is moistened with sterile water and applied to the questioned stain. The reagent is added to the paper or swab and development of an intense purple color noted (Figure 8.10). If an obvious purple coloration does not develop within 2 minutes, the test is recorded as negative. The intensity of the purple color of a positive reaction and the time taken for the color to develop should be recorded. The one-step process of adding reagent directly to a stain or swab *in situ* conveys no advantage if the method described above is correctly applied.

A strong reaction within 30 seconds is diagnostic for semen presence, notwithstanding that identification of spermatozoa or **prostate-specific antigen (PSA)** is the generally accepted standard (see the section below on confirmatory tests for semen). A positive reaction observed in less than 2 minutes in a stain located in an area with little likelihood of containing a contaminant (for example, the knee area of a pair of pants) should also merit confirmation. The forensic biologist must consider the presence of other body fluids, the time elapsed since alleged intercourse, and the fabric type when weak to moderate positive reactions are observed after a minute or so. Vaginal secretions, perspiration, feces, urine, or any combination of these fluids, particularly when repeatedly deposited, will typically exhibit such a reaction, especially in the crotch areas and seams of undergarments. Laboratory policy and individual discretion following thorough review of these issues will dictate whether a confirmatory test is undertaken in these situations.

### *8.3.3 Confirmatory Tests for Semen*

Microscopic identification of sperm cells provides unambiguous proof that a stain under scrutiny contains semen. It is unusual for a forensic scientist to examine semen in which sperm cells are motile since motility is lost within 3 to 6 hours of ejaculation; however, established staining techniques greatly assist the trained eye

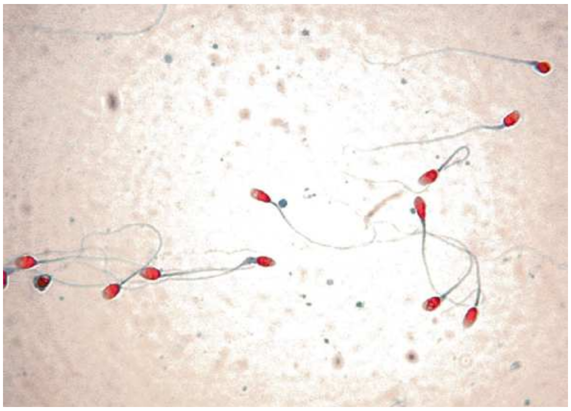


***Figure 8.11*** Human spermatozoa stained with Christmas tree stain (Nuclear Fast Red and picroindigocarmine). (Original magnification 1000×.)

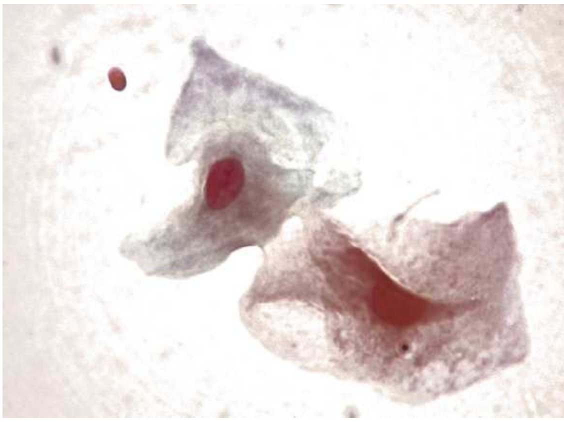


***Figure 8.12*** Human spermatozoon and nucleated epithelial cells stained with Christmas tree stain (Nuclear Fast Red and picroindigocarmine). (Original magnification 1000×.)

to easily distinguish sperm cells from extraneous material such as epithelial cells. The most commonly encountered staining technique uses **picroindigocarmine (PIC)** and nuclear fast red dyes and is colloquially referred to as the *Christmas tree stain*. It was developed specifically for sperm cell visualization. Different parts of the sperm structures are singularly colored and contrast well with the colors taken up by epithelial cells. Stained sperm cells can be identified using microscopy. Sperm cell heads are ovoid and exhibit characteristic differential staining. The anterior portion is pink and the posterior is dark red or purple and often appears shiny (Figure 8.11). Sperm cell tails stain yellow–green and the midpiece stains blue. Epithelial cells also take up the stain and appear blue–green with red nuclei (Figure 8.12).

#### *8.3.3.1 Prostate-Specific Antigen*

You may have heard of the prostate-specific antigen (PSA, p30) test which is used to detect prostate cancer in men. This antigen has also proven to be useful for identifying a stain as semen. In the absence of spermatozoa in an acid phosphatase-positive specimen, the detection of PSA is proof positive for semen. PSA is secreted into seminal plasma by the prostate gland and varies in concentration from 300 to 4000 nanograms per milliliter. Because the prostate gland lies distal to the customary point of interruption in a vasectomy, this procedure has no effect on the elaboration


***Figure 8.13*** Seratec™ PSA test kit. The line closest to the sample well indicates a positive result. The middle line is an internal standard. The line on the left is the positive control.

of PSA into the semen. The urine and serum of males, breast milk, and sweat glands contain levels of PSA that are usually below the limits of forensic detection. PSA is found in elevated levels in the serum of males with prostate cancer, but because a positive AP reaction is usually required in tandem with PSA detection for semen to be unambiguously identified, this, too, is of little consequence forensically. Current tests for PSA are based on the appearance of a blue color as shown in Figure 8.13.

## 8.4 Saliva

Saliva is a slightly alkaline secretion comprised of water, mucus, proteins, salts, and enzymes found in the mouth. Humans produce 1 to 1.5 liters of saliva per day. Its primary purpose is to aid in the initial stages of digestion by lubricating food masses for easier swallowing and initiating the digestion of starches using the enzyme amylase. No test is specific for saliva. Traditionally, forensic tests for saliva relied primarily on the detection of **alpha-amylase**, an enzyme sometimes referred to as *ptyalin* in older references. **Amylases** are ubiquitous enzymes found in both animals and plants. They are responsible for catalysis of the components of starch, amylose, and amylopectin into smaller, less complex sugars. Amylases can be subdivided into alpha and beta categories. beta-Amylases are found in plants and alpha-amylases in animals, including humans. beta-Amylase attacks only the bonds at the ends of polyglucan chains, unlike alpha-amylase, which catalyzes bonds within the chains. Primates, pigs, elephants, and certain rodents have high levels of amylase.

In humans, two DNA loci, AMY1 and AMY2 found on chromosome 1, code for amylase. The AMY1 locus codes for the amylase found in saliva, breast milk, and perspiration. The AMY2 locus codes for the amylase found in the pancreas, semen, and vaginal secretions. In the mouth, alpha-amylase is secreted primarily from the parotid glands as a component of saliva. Although alpha-amylase is found in many body fluids and tissues, it still serves as a good marker because it is found at levels 50 times higher in saliva than in most other body fluids and is relatively stable. Some activity can be detected for up to 28 months.

### *8.4.1 Starch–Iodine Test*

In the presence of iodine, starch appears blue. As amylase acts on starch to break it down, the color changes and subsides. This test has several drawbacks; for example, the presence of proteins, particularly albumin and gamma-globulin originating in other body fluids (e.g., blood, semen), compete with starch for iodine and produce

***Figure 8.14*** Phadebas™ press test. The position of the test paper is marked on the item for accurate relocation.

false positive results. This test is also difficult to use as a locator test for stains on items. One version of this method is still in use as the radial diffusion test. An agar gel containing a known concentration of starch is prepared, and iodine is poured over the gel. An extract of the questioned sample is added to the wells in the gel. As the starch diffuses, it breaks down, leaving a circular void area proportional to the amount of amylase present.

### *8.4.2 Phadebas® Reagent*

More common is the use of commercial products in which starch is linked to a dye molecule to form an insoluble complex. When starch is cleaved from the dye by amylase, the dye molecule becomes soluble, producing a colored product that can be measured with a spectrophotometer. The degree of coloration is proportional to the amount of amylase in the sample. This procedure is commonly referred to as a *tube test*. Alternatively, the reagent can be dissolved and applied to large sheets of filter paper, which can then be placed on an item to map the location of amylase-containing stains for further analysis. This procedure is referred to as a **press test**. Procion red amylopectin (PRA) or Phadebas® reagents are the most commonly used. The Phadebas® reagent is manufactured by Pharmacia and is produced in tablet form. It is used clinically to detect alpha-amylase in urine, serum, and plasma, which may denote certain medical conditions, such as pancreatitis. An example application of the Phadebas® test is shown in Figures 8.14 and 8.15.

## 8.5 Other Body Fluids

### *8.5.1 Urine*

Although the chemical detection of urine may play a role in sexual assault, harassment, and mischief cases, it is performed less frequently by forensic laboratories because of the insensitivity of the tests and the low success rate with DNA profiling. Like many other analyses, detecting urine relies on visual examination for stains with characteristic appearances. Stains may fluoresce or luminesce under alternative light sources, but diluted stains are more difficult to detect. Odor is another

***Figure 8.15*** Phadebas™ press test. A positive reaction appears as a smooth blue region. These areas are circled on the paper and on the item.

characteristic of urine, but it generally permeates an entire item and is not localized to the urine stain itself. Historically, methods for the identification of urine have relied on identifying inorganic ions or organic compounds that concentrate in urine. It is advisable in the forensic context to attempt to identify more than one component for confirmation due to the ubiquity of the substances in question. Urine detection relies on identifying two organic compounds: **urea** and **creatinine**. Both components are found in other body fluids, such as perspiration, blood, saliva, and semen. Urea is present in high levels, approximately 1400 to 3500 milligrams per 100 milliliters. Creatinine is present at about one tenth of these values, with average concentrations of 105 to 210 milligrams per 100 milliliters. While urea and creatinine are found at relatively high levels in liquid urine, they may be difficult to detect in stains, the most commonly encountered forensic samples. As liquid urine is absorbed into fabric surfaces, it spreads across the surface, effectively diluting the test components. Testing for urea relies on the use of urease, an enzyme that breaks down urea and releases ammonia and carbon dioxide. The ammonia is then detected using an indicator chemical, such as Nessler's reagent (mercuric iodide in potassium iodide) or ***p*-DMAC** (*p*-dimethylaminocin-namaldehyde). **Azostix®**, a commercial test strip used for the clinical detection of urea in blood, relies on the same principle, except it measures a shift in pH caused by the formation of ammonia hydroxide.

### *8.5.2 Vaginal Secretions*

The identification of vaginal secretions is especially important when a case involves an allegation of a foreign object inserted into the vagina as part of a sexual assault. Vaginal secretions are usually identified on the basis of detecting glycogenated epithelial cells. A **periodic acid–Schiff (PAS) reagent** serves to stain the glycogen in the cellular cytoplasm a bright magenta color. The cells can then be rated based on staining intensity on a scale of 1 to 4, with 4 being the most intense.

The test is not conclusive as the amount of glycogenation varies depending on the stage in the menstrual cycle; glycogenation levels are highest around the time of ovulation. Glycogenated cells are absent from pre-pubescent females and are uncommon in postmenopausal women, although estrogen replacement therapy will affect the measurement. Glycogenated epithelial cells are also not unique to the vaginal tract and can be found in smaller numbers in the mouth and in the urethral tracts of males. Thus, the finding of only a few cells is problematic for interpretation.

The test may also consume a large amount of the questioned material and reduce the amount available for DNA testing. It may be prudent to forego PAS testing in favor of retaining material for DNA testing. However, if the origin of the cells is particularly important (e.g., whether a DNA profile from a bottle can be attributed to someone drinking from it or from vaginal insertion), this testing may have to be done.

## Chapter Summary

The field of forensic serology has experienced many changes in technology, ranging from simple improvements in technique to the addition of newer methods of analysis and the recognition of additional biochemical sources of information. Twenty years ago the possibility of establishing the degree of identity possible today with DNA and doing it with the minute sample quantity currently used seemed impossible. These kinds of changes are ongoing and do not show any indication of stopping; however, by knowing the past, we can better understand the future. Because the material presented here is a basic primer and not by any means all inclusive, the reader is heartily encouraged to consult additional references for more in-depth information.

## 8.6 Review Material: Key Concepts and Questions

### *8.6.1 Key Terms and Concepts*

ABO blood group system
Absorption elution
Acid phosphatases
Agglutinins
Agglutinogens
alpha-Amylase
Alternative light source (ALS)
Amylases
Antibody (Ab)
Antigen (Ag)
Azoospermia
Azostix®
Benzidine
Chemiluminescence
Chromogenic substance
Confirmatory test
Creatinine
Crystal tests
Enzyme systems
Extracellular fluid
False negative
False positive
Fluorescein
Genetic marker systems
Hemastix®
Hematin
Hemoglobin
Immunological reactions
Lattes crust test
Luminol
Microcrystal tests
Oxidation
*p*-DMAC
Periodic acid–Schiff (PAS) reagent
Phadebas® reagent
Phenolphthalein test (Kastle–Meyer test)
Phosphoglucomutase (PGM)
Picroindigocarmine (PIC)
Platelets
Polymorphism
Precipitin test
Press test
Presumptive testing
Prostate-specific antigen (PSA)
Screening
Secretors
Seminal acid phosphatase (SAP)
Serology
Starch–iodine test
Takayama test
Teichmann test
Tetramethylbenzidine (TMB)
Thrombocytes
Urea

### 8.6.2 Review Questions

1. What two environmental factors are most important to consider in preserving blood evidence?
2. List three possible causes of false positive reactions with presumptive screening tests for blood.
3. Describe the principle behind a presumptive test for blood (what is done and what it means).
4. An analyst conducted a phenolphthalein test on a stain he thought looked like blood. He observed a positive test immediately after adding the phenolphthalein reagent. He concluded that blood was, in fact, present. Was he correct?
5. True or false: Luminol is so sensitive that a positive reaction can be taken to prove that blood is present.
6. A person having the A antigen on his or her red cells will have serum antibodies that will agglutinate cells from:
   _______ a group "A" person
   _______ a group "B" person
   _______ a group "O" person
   _______ a group "AB" person
7. When called to testify regarding evidence he had examined, an analyst was questioned about the possibility of errant enzyme results being introduced into the evidence as a result of inadequate preservation. How should he have responded?
12. Define polymorphism.
13. What are the five classes of serum proteins?
14. Where in the male reproductive tract is acid phosphatase produced?
15. Name two tests considered confirmatory for the presence of semen.
16. Give reasons for the absence of tails on spermatozoa on a microscope slide preparation.
17. How long might seminal fluid constituents be detectable after deposition (a) inside the vagina, (b) in dried form, and (c) on fabric after laundering or dry cleaning?
18. beta-Amylase is found in plants. Will plant extracts or stains react with the Phadebas test? Why or why not?
19. Assume that you detected amylase using a Phadebas press test on a pair of underpants worn after a sexual assault in which cunnilingus is alleged. Discuss the factors that would determine your choice of area for DNA analysis.
20. Why is it preferable to identify both urea and creatinine in suspected urine stains?

## 8.7 References and Further Reading

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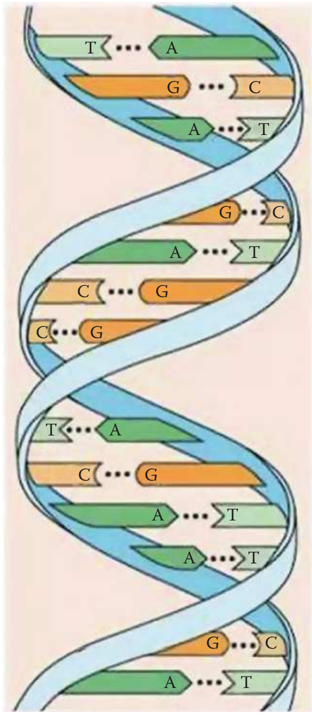
# 9

# DNA Typing




## Chapter Overview

It would be difficult to argue that DNA typing has not revolutionized forensic biology and, in a broader sense, forensic science itself. Building on the foundation of genetics and genetic marker systems, DNA typing has made it possible to identify a person with little or no associated doubt. DNA methods have also driven forensic science to look at all types of evidence in new ways that emphasize technique, validation, proficiency testing, databases, and probabilities. For example, a DNA analyst who testifies on the results of an analysis can say that a given DNA type is expected to be found in one in a trillion (1,000,000,000,000) people, a statement is based on databases of known genetic frequencies. Serological techniques such as ABO and isoenzyme typing could also provide probabilities, but they are often on the order of percent (e.g., one person in 100 as we saw in Case Study 8.1). Given that the population of the world is about 7 billion, a probability of one in a trillion carries much more evidentiary weight than one in a hundred. This chapter explores the history and development of DNA typing and discusses the many ways it can be used. Many of these applications are stretching the traditional boundaries of forensic science.

# Chapter 9
# DNA Typing*

*George T. Duncan, Martin L. Tracey, and Éric Stauffer*

## Chapter Outline



## 9.1 Inheritance of DNA Characteristics

The DNA molecule is the currency of genetics. Recall that DNA is a long double-stranded molecule that in the cell is found in a twisted ladder shape referred to as a double helix. A great deal of laboratory testing, including separation and identification of DNA, depends upon the mirror-image structure of DNA. Its double-stranded complementary structure encodes the information required to make new copies of itself. (For a discussion of career preparation for this field, see Sidebar 9.1.) The intact DNA molecule is composed of adenine (A), thymine (T), cytosine (C), and guanine (G) **nucleotides** (Figure 9.1). A nucleotide is defined as the unit consisting of the base (A, C, G, or T) connected to a sugar molecule and phosphate group. The sugar and the phosphate group constitute the backbone of the helix. The complementarity of the two halves of the molecule or the two strands depends on the simple fact that A only pairs with T, and C only pairs with G, except during mutation.

About 60 years ago, an English graduate student named Francis Crick and an American postdoctorate researcher named James Watson first proposed that the structure of DNA was a double-helix. The two individual strands curl around each other in a shape of a twisted ladder. The significance of Watson and Crick's DNA

* This chapter is based on Chapter 13, "Techniques of DNA Analysis," by George Duncan, Martin Tracey, and Éric Stauffer, as published in the second edition of this text.

**SIDEBAR 9.1. CAREER PREPARATION AND EXPECTATIONS**

The entry level requirement for DNA analysts is typically a bachelor's of science degree in a science such as chemistry or biology. In addition, the DNA Advisory Board stipulates that analysts must complete courses in "biochemistry, genetics and molecular biology (molecular genetics, recombinant DNA technology) or other subjects which provide a basic understanding of the foundation of forensic DNA analysis, as well as course work and/or training in statistics and population genetics as it applies to forensic DNA analysis." (http://www.cstl.nist.gov/strbase/dabqas.htm). This is the first forensic discipline with such a universal requirement for career preparation. Once hired, analysts undergo a lengthy training program that can stretch over more than a year before they begin doing independent casework. In most labs, DNA analysis is a full-time position, and forensic scientists working in this area do not work on other types of cases.

model has been enormous in the field of biology (Figure 9.2). In addition to opening the doors for nearly every breakthrough concerning our understanding of DNA replication, transcription, and translation, Watson and Crick helped us to understand how we can manipulate DNA to perform the tests that have become central to any forensic investigation. Figure 9.3 is a timeline of the development of genetics and forensic applications of genetics including DNA.

We inherit the information required to produce all our characteristics in the form of DNA. We do not inherit the characteristics—only the information to produce them. The rules of inheritance are simple. We inherit half our genetic material (DNA) from each parent. When the egg and sperm unite at fertilization, a new, unique individual is created. Like her parents, this individual, if female, has two copies of all the genetic material and she can produce eggs that will contain only one copy of each gene. If the child is male, he, too, has two copies of each gene but can pass only one of the two to each of his progeny. Most cells have a nucleus containing chromosomes. Normally, we all have 23 pairs of chromosomes, including the gender chromosome called the X and Y chromosome. Why pairs? For each chromosome, we inherit one from our mother

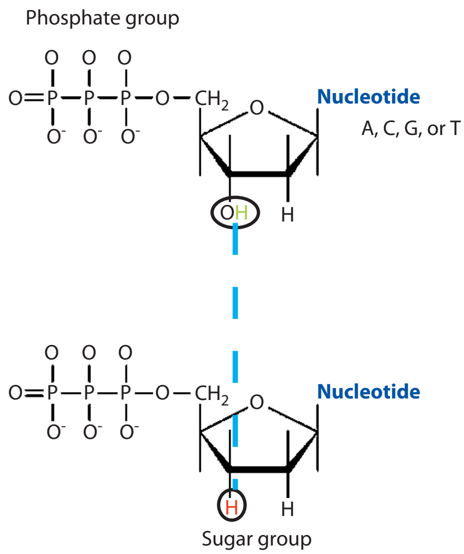



*Figure 9.1* DNA molecule.

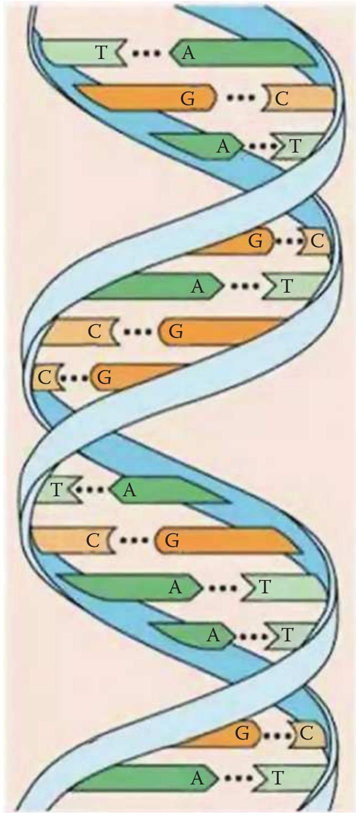



***Figure 9.2*** Watson and Crick's DNA model was an enormous breakthrough for the field of biology.

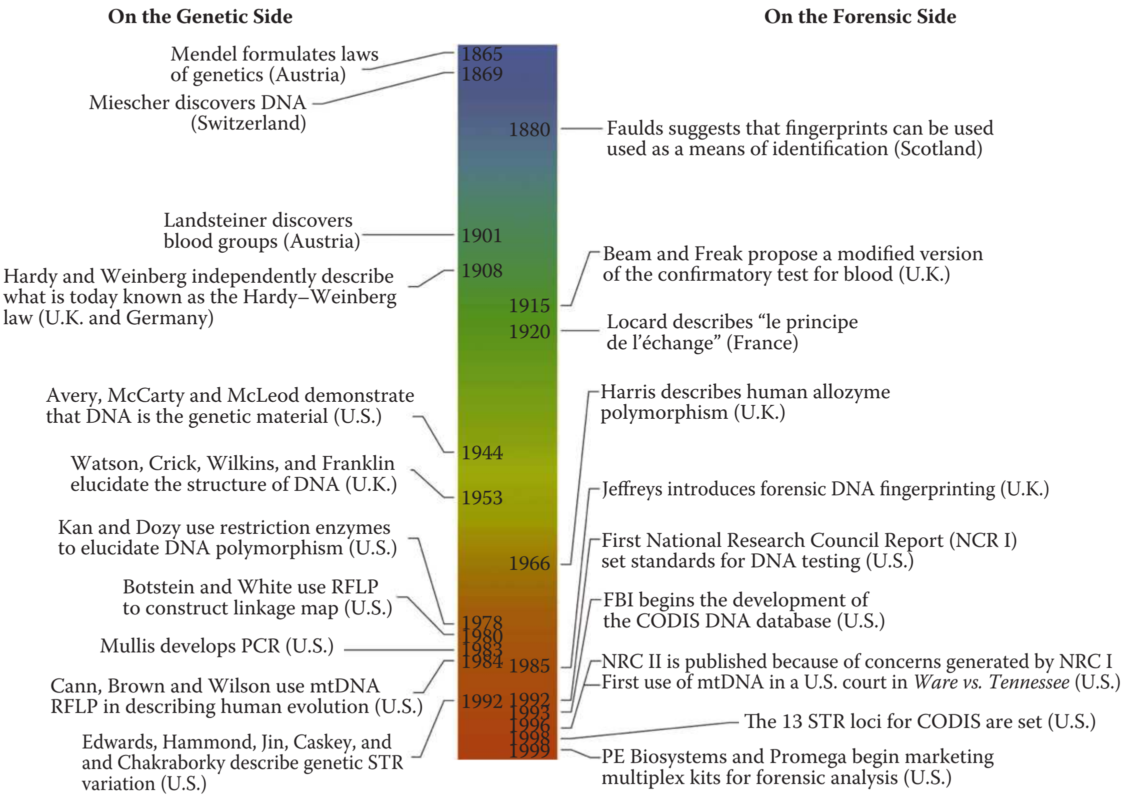



***Figure 9.3*** Timeline of development of genetics and forensic applications of genetics, including DNA.

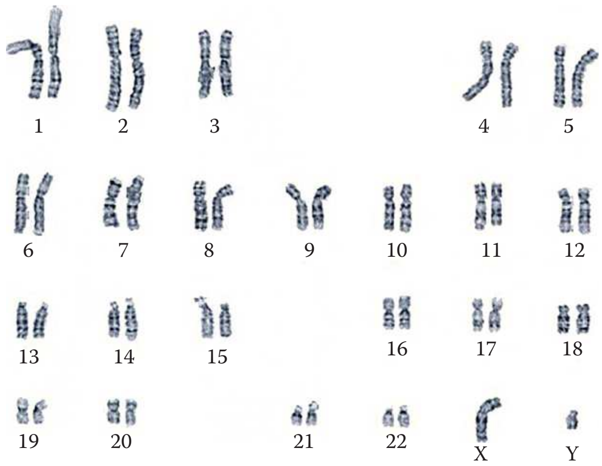



***Figure 9.4*** Males inherit one X chromosome from the mother and one Y chromosome from the father.

and one from our father. If we are female, we will inherit an X from our mother and an X from our father. If we are male, we will inherit one X chromosome from our mother and one Y chromosome from our father (Figure 9.4). Mature red blood cells, although important, do not have a nucleus and therefore lack nuclear DNA.

## 9.2 How DNA Made It into the Courts

In November 1983, a 15-year-old schoolgirl Lynda Mann was raped and strangled on the Black Pad footpath in Narborough, Leicestershire. Despite a massive manhunt, the murder went unsolved. A few years later, on July 31, 1986, another 15-year-old schoolgirl, Dawn Ashworth, was raped and strangled nearby on Ten Pound Lane near a psychiatric hospital. A cook at the psychiatric hospital eventually confessed to the second murder. Police collected over 4500 voluntary samples from local men between the ages of 16 and 34 from three villages. **Sir Alec Jeffreys**, a geneticist at Leicester University had recently developed DNA testing (Figure 9.5). Jeffreys performed DNA tests at Leicester University on the evidence samples and found that the same man had committed both murders and that man was not the cook.

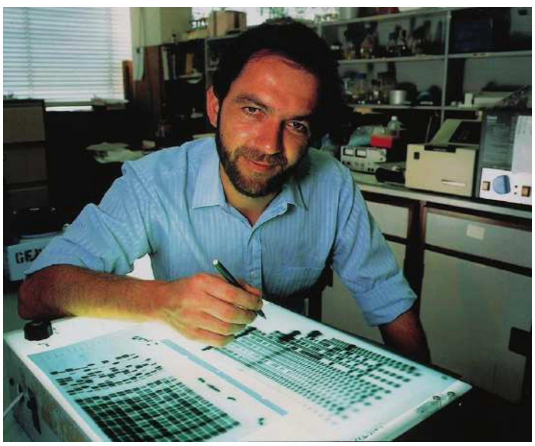


***Figure 9.5*** Sir Alec Jeffreys was responsible for significant developments in the area of DNA testing.

**Colin Pitchfork**, a local baker and convicted flasher, married with children, had avoided taking the voluntary blood test by having a coworker take it for him. No matches were found between the sperm taken from both victims and the 4500 men tested. Then, in September 1987, another coworker tipped off police. The police immediately arrested Colin Pitchfork. When they asked him why he had done it, he stated because they were there. In January 1988, Colin Pitchfork became the first criminal caught with DNA evidence and was sentenced to two life sentences. The judge said that without DNA Colin Pitchfork would still be out there murdering young girls. The cook who had confessed to the second murder became the first suspect exonerated with DNA. Other example cases are presented in Case Study 9.1 and Case Study 9.2.

### CASE STUDY 9.1: *STATE V. JOHN NICHOLAS ATHAN*

DNA evidence is proving invaluable in cold-case investigations. On November 12, 1982, in Seattle, Washington, police found the body of a 13-year old girl inside a cardboard box dumped behind a Seattle store. Except for a pair of socks, her body was nude from the waist down and the cause of death was strangulation. A ligature was found around her neck. Although no DNA was found under her fingernails, there was evidence of rape occurring near the time of the murder. The medical examiner found spermatozoa on the rape kit vaginal swabs. The girl's body was found near the residence of an acquaintance, 14-year-old John N. Athan. Although John N. Athan's brother reported that he had seen John pushing a large box on a shopping cart near the area where the victim's body was found, John N. Athan denied having sex with the victim. There was no confession, there were no eyewitnesses, his fingerprints did not match fingerprints found near the crime scene, nothing placed the two together, and DNA profiling was not yet available. Therefore, the case remained unsolved for over 20 years until 2003, at which time, due to advances in DNA technology and creation of a new cold case homicide unit, Seattle police detectives submitted the old crime scene evidence for DNA testing and a male profile was developed. Next, posing as a fictitious law firm, the Seattle police detectives sent John N. Athan a letter, along with a return envelope, stating he was eligible for money and inviting him to join a fictitious class action lawsuit over parking tickets. He licked the envelope and returned the letter, and detectives opened the letter without a warrant or court order. The Washington State Patrol Crime Laboratory obtained a DNA profile from saliva on the return envelope and compared the DNA profile to a DNA sample from the 21-year-old crime scene rape kit. The DNA profile obtained from the letter returned to the fictitious law firm matched the sperm fraction, a male DNA profile generated from the vaginal swabs, and John Athan was charged and arrested in New Jersey. A search warrant for his DNA obtained a DNA profile that also matched the DNA profile on the envelope and the male sperm fraction DNA profile on the vaginal swab. Back in Washington, John N. Athan was convicted of second-degree murder the following year, in 2004. In 2007, the Washington Supreme Court upheld John N. Athan's conviction and held that, under these circumstances, any privacy interest in his saliva was lost. The court decided that the envelope, and any saliva contained on it, became the property of the recipient.

By the time Colin Pitchfork was being sentenced to life in prison, DNA was being introduced in courtrooms in the United States. By 1986, a few commercial companies in the United States were able to perform DNA profiling. By 1988, the Federal Bureau of Investigation (FBI) also had that capability. The earliest DNA profiling tests, identical to the tests performed in the Leicestershire murder inquiry, required large samples and worked poorly with small or degraded samples. The FBI began training local state crime laboratory analysts in DNA profiling, and local state crime laboratories soon ran their own DNA tests. They compiled convicted offender databases and tied into the FBI's national system known as CODIS (Combined DNA Index System), which remains the DNA database in the United States.

## 9.3 DNA Typing

The haploid human genome (contained in a sperm or egg cell) contains approximately 3 billion **base pairs (bp)** with four different bases possible at each site, as mentioned above (A, T, C, and G). Human genomic DNA may encode for less than 20 to 25 thousand genes, while the remainder is noncoding DNA, sometimes known informally and a bit misleadingly as "junk" DNA. The DNA sequences that code for proteins make up only approximately 3% of human genomic DNA. The remaining 97% are noncoding regions (i.e., they do not code for proteins). Much of this noncoding DNA sequence is repetitive; the same sequence is repeated over and over, either in a tandem array or dispersed over the chromosomes. Interspersed repetitive sequences are distributed throughout the genome and are found between and sometimes, rarely, in the coding regions. These interspersed repetitive sequences account for about 50% of the human genome. Many different kinds of repetitive regions are distributed throughout the genome; we will focus our attention on one type. Simple sequence repeats such as **microsatellites** and **minisatellites** are known as **short tandem repeats (STRs)** and **variable number tandem repeats (VNTRs)**. They are components of the repetitive DNA known as **satellite DNA**.

### *9.3.1 Microsatellites*

Several kinds of tandem repeats are characterized by particular kinds of satellite DNAs. One class consists of short sequence repeats (2 to 20 bp units) and another consists of complex sequence repeat units (100 bp units). Microsatellite repeats comprise a simple class that consists of 2 to 7 base pairs in each tandem repeat unit called short tandem repeats (STRs). Minisatellite repeats have been described from 9 to 80 bp. Figure 9.6 shows several tandem repeats that are of forensic interest.

The number of these repeating units is highly variable, and most people have differing numbers of these allelic repeat units inherited from their mothers and fathers. As an example, assume that a given sequence is repeated 5 times in the DNA carried in the sperm and 12 times in the DNA carried by the egg. The child will have a genotype/phenotype of 5,12 when the two separate strands combine when the egg is fertilized. This repeat length difference is a chance phenomenon, dependent on the number of allelic length variants at a particular locus or gene. **Heterozygosity** is when an individual has two different copies (or alleles) of a gene or locus, such as in the 5,12 example. A person who has the same number of copies at both loci such as 12,12 is **homozygous**. These repeating sequences are excellent tools for assessing differences among humans because of their high level of variability or

### CASE STUDY 9.2: THE DISAPPEARANCE OF JESSICA O'GRADY

Is it possible to prosecute someone for murder when the victim's body has not been recovered? It is difficult, but not impossible. On May 10, 2006, a 19-year-old University of Nebraska student, Jessica O'Grady, was last seen leaving her apartment in Omaha, Nebraska, to visit a former boyfriend to inform him that she was pregnant with his child. The Omaha Police Department and the Douglas County Sheriff's Office conducted a series of searches around Omaha and Douglas County but found no trace of Jessica. Her body was never recovered. Was she murdered or did she simply vanish (Figure CS9.2.1)?

Jessica had recently been dating Christopher Edwards. Edwards lived with his aunt and had another girlfriend at the time Jessica O'Grady disappeared. The Douglas County Sheriff's Office received the case and began their investigation. They interviewed Christopher Edwards. On May 16, 2006, the Douglas County Sheriff's Office CSI unit searched Edwards' aunt's home. In Christopher Edwards' bedroom, they noticed a red stain on the foot of the mattress. Lifting the mattress, they discovered a large, saturated bloodstain on the underside (Figure CS9.2.2).

The Douglas County CSI unit also observed blood spatter on the headboard of the bed, the box spring, and the bookcase in the bedroom. They found cast-off bloodstains on the ceiling. A Bangkok battle sword with reddish staining was located in his closet. In the trash at the residence, the CSI unit found a bloodstained towel. In Christopher Edwards' car, the CSI unit found a pair of bloodstained hedge shears and bloodstains on the metal frame of the trunk. The CSI unit collected all of this forensic evidence.


***Figure CS.9.2.1*** University of Nebraska student Jessica O'Grady's body was never recovered after she vanished in May 2006. (Courtesy of David Kofoed, Douglas County Sheriff's Office, Omaha, Nebraska.)

***Figure CS.9.2.2*** Bloodstains found on the underside of Christopher Edwards' mattress matched the DNA profile of Jessica O'Grady, linking Edwards to her death.

***Figure CS.9.2.3*** A mixture of both Christopher Edwards' and Jessica O'Grady's DNA profiles on the handle of the sword linked Edwards to O'Grady's death.

DNA testing was performed at the University of Nebraska Medical Center's Human DNA Identification Laboratory. When no body has been recovered, the forensic laboratory needs something belonging to the victim or a DNA sample from a close family member to determine the missing victim's DNA profile. In this case, O'Grady's personal items, including a hairbrush, underwear, and a razor, were used to create a DNA profile. Her DNA profile was then compared to the DNA profiles obtained at the crime scene and the DNA profile of Christopher Edwards. Not all of the samples collected yielded a result; however, the DNA profile results from the bloody mattress matched the DNA profile of Jessica O'Grady. Other blood evidence found on the ceiling, walls, mattress, hedge clippers, and bath towel also provided profiles of DNA that matched Jessica O'Grady's. The DNA profile on the black handle of the Bangkok sword was consistent with a mixture of DNA from Jessica O'Grady and Christopher Edwards (Figure CS9.2.3).

This was the first murder case prosecuted without a body in Douglas County, Nebraska. Although Jessica O'Grady's body has never been found, Christopher Edwards was convicted of second-degree murder in 2007 and was sentenced to 100 years in prison.

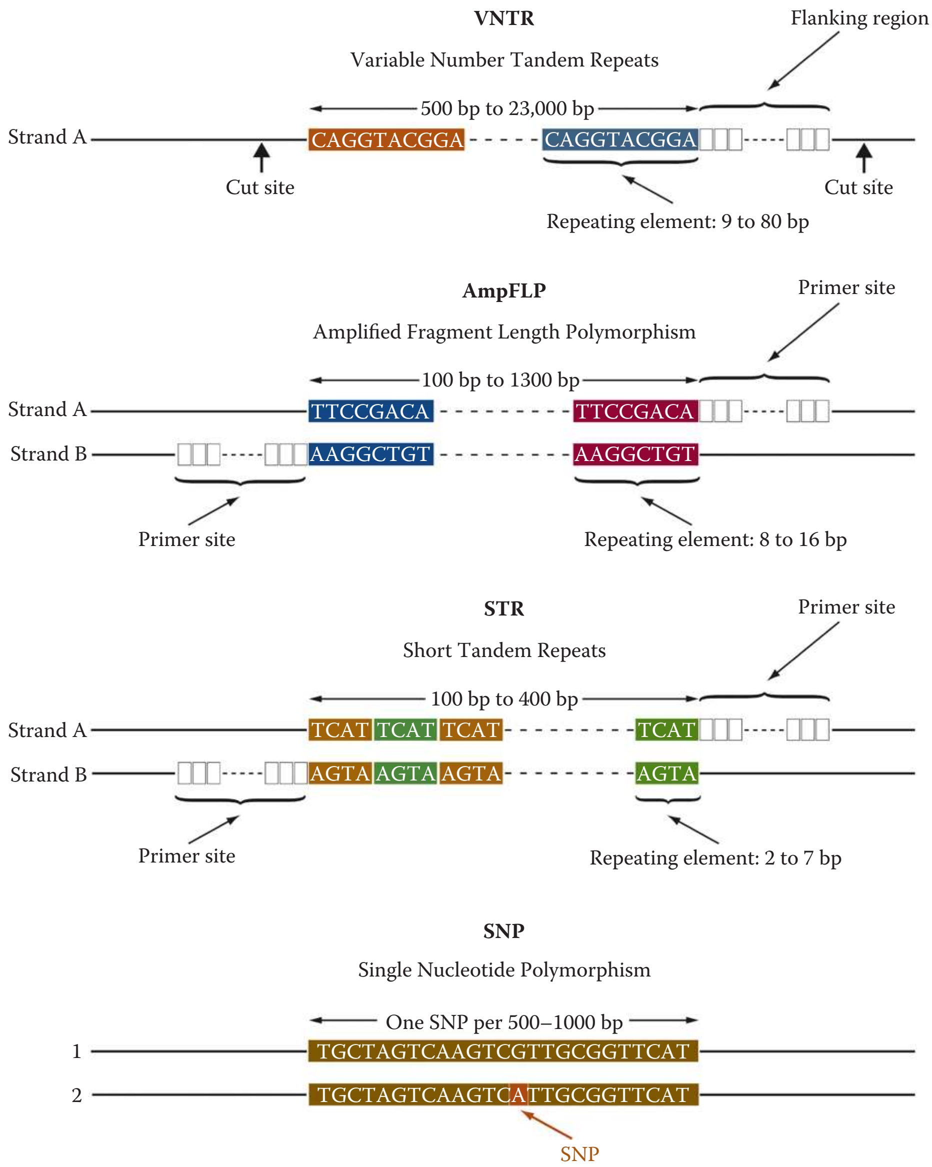



***Figure 9.6*** Different types of repeating base pair sequences found in DNA.

polymorphism. By use of techniques such as restriction fragment length polymorphism (RFLP) and short tandem repeat (STR) analysis, a forensic scientist can estimate the lengths of these variable number tandem repeats (VNTRs, micro or minisatellite) and use them to identify with precision and accuracy the identity of an individual. The RFLP technique was the first developed and was used by Sir Alec Jeffreys in the case just described. However, this method has been replaced by typing of STRs in most forensic laboratories (see Sidebar 9.2).

### *9.3.2 Samples and Sample Preparation*

Because an individual's unique set of DNA molecules is housed within the nuclei of all types of cells in the human body except mature red blood cells, scientists can rely on different tissue sources for DNA collection. Nucleic acid is usually extracted from blood, semen, bone, hair, and dried skin; these are the sources for most crime scene DNA isolations. DNA is a very long polymer, as shown in Figure 9.6. Human cells contain 46 nuclear DNA molecules; each is composed of millions of nucleotide pairs. These long DNA chains are susceptible to degradation. Breakdown of DNA into 50,000 (50 kilobases or Kb) bp fragments during typical isolation procedures is almost inevitable. Size is not usually a major factor in PCR testing, as small fragments of less than 1000 bases are needed for analysis. Enzymes called **nucleases** are responsible for most of the environmental breakdown of DNA. These substances are found nearly everywhere, including on the surface of our skin, where they protect us from foreign DNA invasion. Several factors are known to contribute to DNA breakdown. Tissue samples that are dried as soon as possible are most suitable for DNA profiling. Many degradative processes require the DNA to be hydrated (surrounded by water); if the DNA is not in solution, it retains its integrity longer. When samples arrive in the lab, it must be decided whether DNA isolation will begin immediately. If circumstances do not permit DNA purification, dry samples are stored frozen or at room temperature in a dry environment, and wet samples are frozen.

There is no single best technique of DNA isolation, and often the method of choice is dictated by the tissue type to be analyzed. As one example, blood may be mixed with a solution containing salt, detergent, and an enzyme that breaks down proteins. Enzymes that digest proteins are referred to as *proteinases*. Although many proteinases exist, the one that is routinely used is proteinase K because of its efficiency, availability, and cost. By digesting proteins into smaller subunits, DNA is released from other cellular compartments. Protein digestion and actions of detergents during the extraction process destroy the plasma membrane (the outermost boundary of the cell) and the nuclear membrane that surrounds the DNA. This, in effect, allows the DNA to go freely into the reaction solution.

### *9.3.3 Making Multiple Copies of DNA; PCR*

A great deal of laboratory testing, including separation and identification of DNA, depends on the double-stranded structure of DNA. Its complementary structure encodes the information required to make new copies of itself. Each half strand of a DNA molecule may be envisioned as long strings of these four bases represented as letters, for example:

… A–A–T–G–G–C–A–T–T–G–G–G–C–T–A–A–T–C–G–T …

The complementarity of the two halves of the molecule or the two strands depends on the fact that A pairs only with T, and G pairs only with C, except during mutation. Using these pairings, we can easily predict the sequence of bases in the strand complementary to that above:

… T–T–A–C–C–G–T–A–A–C–C–C–G–A–T–T–A–G–C–A …

This complementary nature is exploited during PCR cycling in which the DNA is heated to approximately 95°C to break the connecting bonds and produce separate strands, each constituting of a half molecule of DNA:

… A–A–T–G–G–C–A–T–T–G–G–G–C–T–A–A–T–C–G–T …

and

… T–T–A–C–C–G–T–A–A–C–C–C–G–A–T–T–A–G–C–A …

**SIDEBAR 9.2. HISTORICAL NOTE: RFLPS**

Although STRs are the most commonly used targets in DNA typing, they are not the only ones. The first DNA tests developed by Sir Alec Jeffreys in 1984 were known as restriction fragment length polymorphism (RFLP) tests, and that was the method used in the Pitchfork case. RFLP analysis allowed for measurement of the size of DNA fragments. Analysts could compare the sizes of fragments from a known reference and a crime scene sample in order to match two DNA profiles. RFLP is based on a variation in the number of times a sequence of base pairs in DNA is repeated, much as with STRs; however, RFLP fragments are considerably longer than STR repeats.

As in any analysis of DNA or biological stain, the material in question must be extracted and isolated from the evidence. Once this is accomplished, the restriction enzymes are added that cut the DNA into fragments in which the repeated segment occurs. The smaller fragments have fewer repeats; the larger fragments have more repeats. Using gel electrophoresis, the fragments are separated based on size, with the smaller fragments traveling farther than the larger fragments. On each gel, controls are used, including an "allelic ladder," which allows the analyst to gauge the number of repeats found in the evidence by comparing the gel position of the evidence sample with the allelic ladder. Once electrophoresis is complete, the fragments have been separated but are still not visible. The next step is to transfer the DNA to a nylon membrane using a technique called *Southern blotting*. To visualize the bands now on the nylon (which resemble a barcode), radioactively labeled probes are placed in contact with it. The probe bonds to the fragments, along with the radioactive label in a process called *hybridization*. The final step is to expose x-ray film over the nylon membrane, which will show bands wherever there is radioactivity. Types are read from the x-ray film, which is called an *autoradiograph* or *autorad* (Figure S9.2.1).

Restriction fragment length polymorphism is a powerful discriminating tool, but there are some disadvantages. Because the fragments are relatively long (thousands of base pairs), they are subject to degradation. Older cases or cases

This strand separation process is called **denaturation** or *melting*. Now each half of the separated DNA molecule can serve as a template for making a copy:

5′ … A–A–T–C–C–G–T–A–A–C–C–C–G–A–T–T–A–G–C–A … 3′3′
… T–T–A–G–G–C–A–T–T–G–G–G–C–T–A–A–T–C–G–T … 5′

splits into its halves:

5′ … A–A–T–C–C–G–T–A–A–C–C–C–G–A–T–T–A–G–C–A … 3′

and

3′ … T–T–A–G–G–C–A–T–T–G–G–G–C–T–A–A–T–C–G–T … 5′

The strands are labeled 5′ (five prime) to 3′ (three prime). The conventional way to mark the strands as to their orientation is by indicating particular carbon atoms in the molecule.

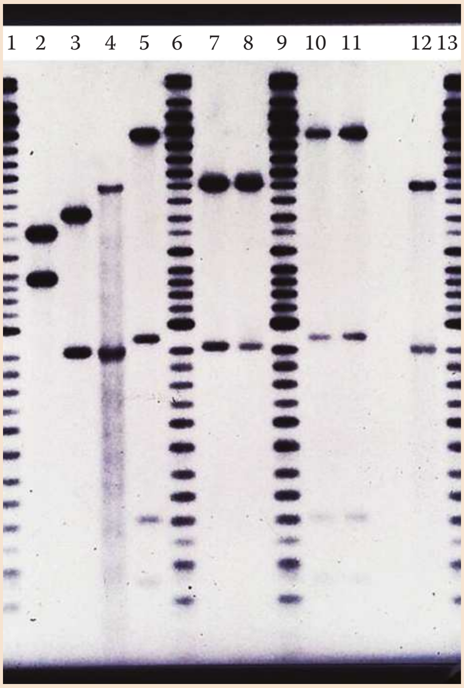



***Figure S9.2.1*** Restriction fragment length polymorphism (RFLP) testing allows analysts to match two DNA profiles based on the size of DNA fragments.

in which blood or body fluid evidence has decayed are questionable for RFLP. RFLP tests are labor intensive, require large sample sizes (blood, spermatozoa, skin), and take several weeks to perform. Because of the difficulty and expense of RFLP testing, it has become obsolete. Many crime scene samples are too small for RFLP tests—a speck of blood on a suspect's shoe or skin cells deposited on the handle of a murder weapon are not sufficient to provide RFLP results. The use of STRs and PCR has generally replaced RFLP in forensic DNA typing.

Copying DNA is conceptually simple. The steps are as follows (see Figure 9.7):

1. Obtain a sequence of double-stranded DNA.
2. Split it into separate strands.
3. Synthesize new complements.

The copying of DNA in this way is an exponential or chain process. If we start with one double DNA strand, we will have two intact DNA molecules after one pass through the three steps above. Another cycle through the three steps, beginning with two DNA helices (the two original DNA strands and the two produced in the previous cycle), yields four helices. Another cycle will yield eight, another cycle will yield 16, another will yield 32, etc. After only 30 cycles through the three-step process of DNA amplification, we will have more than a billion copies of the initial DNA molecule, assuming 100% efficiency of the process (Figure 9.8). If this sounds unlikely, test it by continuing to double the number of DNAs starting where we left off (keeping in mind that each "original" will replicate itself): 32 molecules will

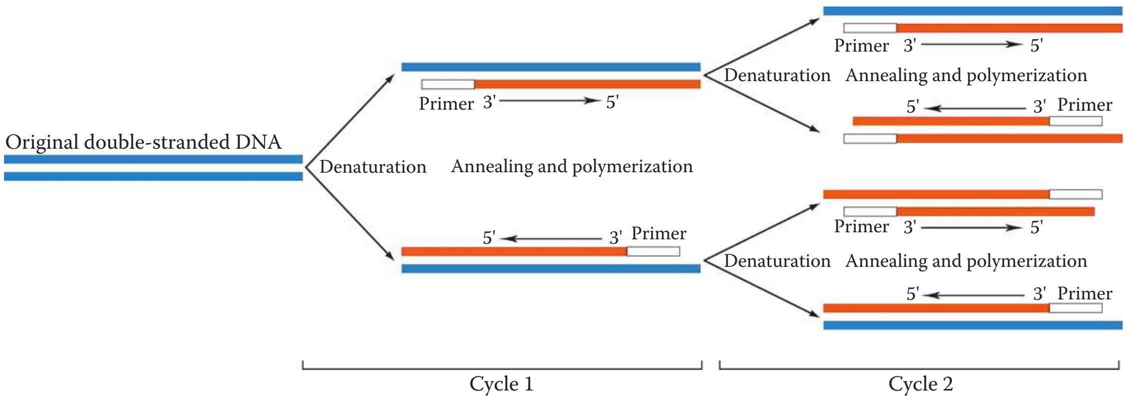



***Figure 9.7*** Steps in the amplification (copying) of segments of DNA using PCR.

produce 64; 64 will produce 128; 128, 256; 256, 512; 512, 1024; 1024, 2048; 2048, 4096; etc. This is the essence of the biotechnological process of DNA amplification or the **polymerase chain reaction (PCR)**.

Polymerase is the enzyme that attaches the new bases (the lowercase letters) onto the template strands. Polymerase is only one of many chemicals required to make the process work, but the details are not important to an understanding of PCR. All we need to know is that (1) DNA is composed of two half-molecules that copy themselves on the basis of A–T and G–C complementarity, and (2) we must have an enzyme, a polymerase, that can stand the 95°C heat used to separate the two DNA strands (denaturation). This is the key to the laboratory use of DNA replication as a tool for forensics, medicine, etc. Most **DNA polymerases** function at normal body temperature, 37°C (98.6°F). Like most proteins, they lose function and fall apart at 95°C. Thus, scientists were unable to amplify DNA in an efficient manner, until other scientists working with **Kary Mullis** at Cetus Corporation decided to check the toughness (thermostability) of DNA polymerases from bacteria that live in hot springs. Dr. Mullis was awarded the 1993 Nobel Prize in chemistry for "contributions to the developments of methods within DNA-based chemistry," specifically for his invention of the polymerase chain reaction (PCR) method (http://

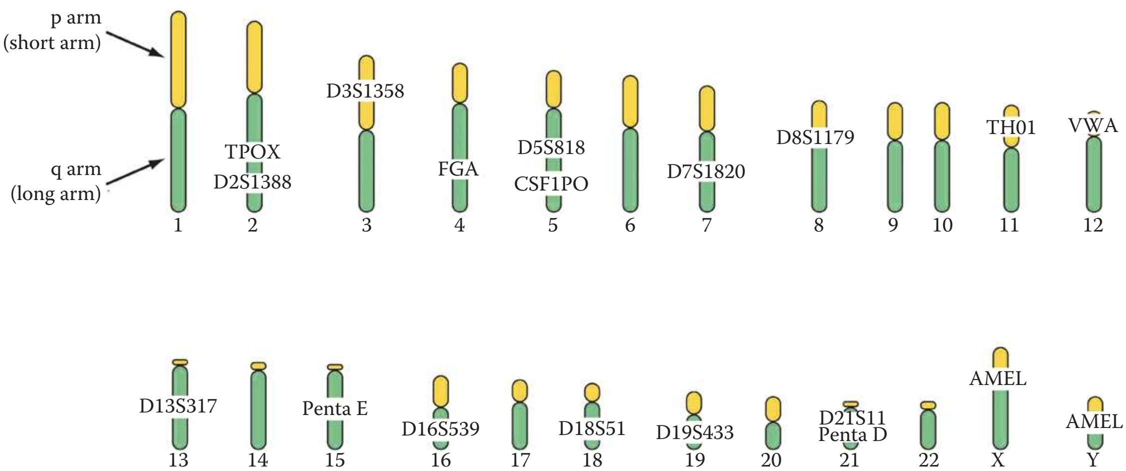



***Figure 9.8*** Loci that can be typed using different commercial kits.

www.nobel.se/). The hot springs polymerases could stand the 95°C heat required to split DNA into its two strands, and this meant that the process could be automated. DNA could now be copied over and over and scientists could produce as much DNA as required.

After 20 to 30 rounds of DNA copying, we will have millions of identical copies of the original or target piece of DNA. These copies are known as **amplicons**. Depending on the particular polymerase enzyme used, the amplicons range in size from as small as several nucleotides to as many as 20,000 or 30,000 nucleotides in length. The choice of specific sequences is a technical matter of primer selection.

A primer is, as the name suggests, a necessary ingredient for beginning the DNA replication process. Primers specifically define which region of the DNA will be amplified through base pair complementarity. As described earlier, half of the molecule serves as a template to produce its own complement. However, the new strand cannot form without an anchor set of nucleotides already on the template to which the new nucleotides may be added by the polymerase. Suppose we wish to amplify the DNA between the T–G–G–C–A–T and the T–A–A–T–C–G shown below, where N represents the bases that we want to amplify:

Strand 1: 5′ T–G–G–C–A–T–N–N–N–N–N–N–N–N–T–A–A–T–C–G 3′
Strand 2: 3′ A–C–C–G–T–A–N–N–N–N–N–N–N–N–A–T–T–A–G–C 5′

(represented by strand 1) in our example. We would add the primers 5′ t–g–g–c–a–t 3′ (the complement of our selected strand 2 sequence) and 5′ c–g–a–t–t–a 3′ (the complement of the strand 1 sequence) to the reaction mixture (remember to orient the 5′ primer to the 3′ end of the sequence). These primers will bind only to their specific complements; the polymerase will fill in the missing nucleotides between the two primers.

The PCR process consists of three major steps: denaturing, annealing, and extension. This process is repeated 20 to 30 times. The denaturing step is the separation of the two strands of the DNA molecule. This makes both strands available for further amplification once the strands or templates are primed. This strand separation occurs when the DNA double helix is heated between 94 and 96°C, at which point single-stranded DNA primer sequences from 6 to over 39 base pairs bind to the sequence exterior (**flanking region**) of the target we want to amplify.

Primer binding is also called **annealing** (55 to 72°C). Next, a thermostable DNA polymerase adds bases such as A, T, G, or C to the single-strand template, thus making a new complementary single strand. The primer initiates the extension (72 to 75°C) process. Because primer sequences are present in vast excess, the process may be repeated over 2 to over 30 cycles, thus creating millions of copies via an exponential chain reaction. This yields the DNA required for comparative size or length analysis.

## 9.4 Short Tandem Repeats

Short tandem repeats are the current standard in forensic genetic typing. Most scientists formerly believed that these and other kinds of repeats had no functions. As of late, some have speculated that they may, in fact, have a role to play in genome structure and function. Certain regions of the genome play roles in building the chromosomal scaffold/matrix associated regions. These regions provide a framework for the many complex physical and chemical functions of the cell. It has been conjectured that repeats may have some role in this organization. Part of that organization and an issue that is important in chromosomal functionality is the organization of the chromatin.

Short tandem repeats usually consist of repeated **tetramers** (tetranucleotides); that is, they have four bases that are repeated as in an array. STRs are important in forensic science, as they can be readily amplified as previously described. They are small, in that most have less than 40 repeats in all. Including their flanking regions, they are only 300 to 400 bp in size—a reasonable length for a PCR amplicon. Many newer polymerases on the market may amplify many thousands of base pairs fairly easily in one amplification reaction. STRs are also very useful in forensic science as they vary in the number of repeats each person inherits from his or her parents. In the mid-1990s, 13 core loci were chosen as the standard loci to be typed and used in CODIS (Figures 9.8 and 9.9).

Many methods are now available to analyze STRs. Some older methods rely on gel-based instrumentation genetic analyzers to perform an analysis on amplified products to determine the DNA profile of the sample. Newer methods employ **capillary electrophoresis** units which allow for fast and automated methods for genetic profiling with the use of a small capillary, a little larger than the width of a human hair and about 20 centimeters in length, to separate the various fragments allowing for genotyping of a sample. With capillary electrophoresis, the DNA is detected by **laser-induced fluorescence (LIF)**. For this to work, the amplicons are labeled with one of four fluorescent dyes. The sample is injected into the capillary, which has a positive charge at one end and a negative charge at the other end. The amplicons are separated in the capillary based on their relative sizes and charges. At the end of the column, the amplicons pass by a small window illuminated by a laser. The laser causes the dyes to fluoresce, generating an intense, color-coded signal. An example is shown in Figure 9.10. The top frame shows all of the amplicon peaks on the output of the electrophoresis instrument. Notice that there are four "panels"

**AmpFLSTR® Identifiler**

13 loci CODIS

**PowerPlex® 16 System**

| Locus | Repeat Sequence | Known Repeats | Commercially Available Sizes | Chromosomic Location |
|---|---|---|---|---|
| **D2S1338** | TGCC, TTCC* | 15–28 | 289–341 | 2q35–37.1 |
| **D19S433** | AAGG | 9–17.2 | 106–140 | 19q12–13.1 |
| **CSF1PO** | AGAT | 6–15 | 280–327 | 5q33.3–34 |
| **FGA** | CTTT* | 15–30 | 206–266 | 4q28 |
| **D3S1358** | GATA | 9–20 | 101–145 | 3p |
| **D5S818** | AGAT | 7–15 | 119–166 | 5q21–q31 |
| **D7S820** | GATA | 6–14 | 215–289 | 7q11.21–22 |
| **D8S1179** | TCTA* | 8–18 | 127–167 | 8 |
| **D13S317** | TATC | 7–15 | 165–233 | 13q22–q31 |
| **D16S539** | GATA | 5.8–15 | 233–304 | 16q22–24 |
| **D18S51** | AGAA | 9–27 | 272–344 | 18q21.3 |
| **D21S11** | TCTA* | 24–38 | 186–242 | 21q21 |
| **THO1** | TCAT | 3–13.3 | 160–214 | 11p15–15.5 |
| **TPOX** | AATG | 6–14 | 217–256 | 2p23–2pter |
| **VWA** | TCTA* | 11–22 | 127–200 | 12p12–pter |
| **Penta D** | AAAGA | 2.2–17 | 376–441 | 21q |
| **Penta E** | AAAGA | 5–24 | 379–474 | 15q |

***Figure 9.9*** Human chromosomes with the loci currently typed shown.

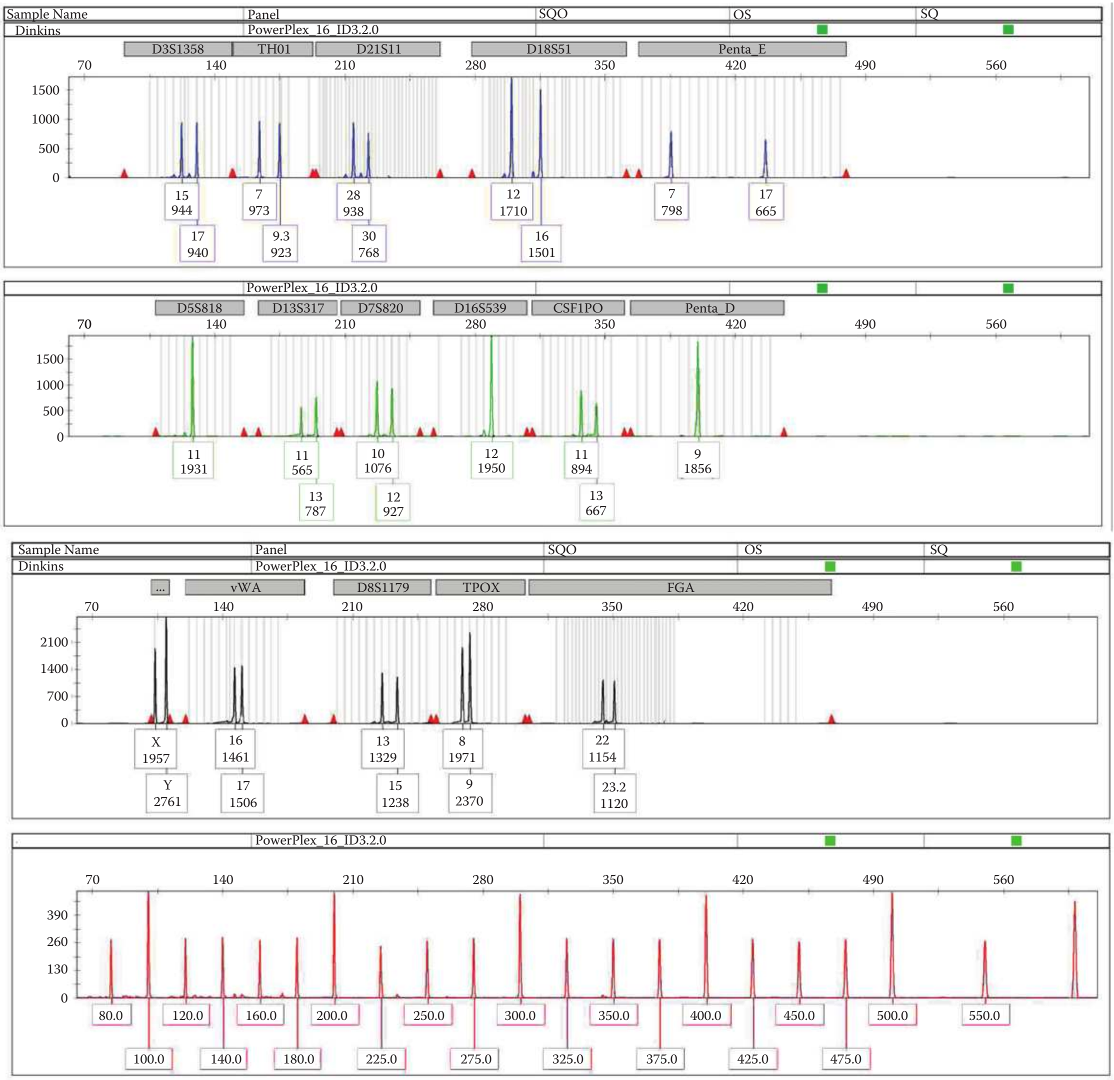



***Figure 9.10*** Example output of a capillary electrophoresis typing analysis. (Image courtesy of Tina Moroose, West Virginia University.)

that are associated with the color of the fluorescence. This makes it easy to isolate each locus in the output. The lower frame gives an idea of the size of the bp units that are being detected. Also, notice that in the third panel the first two peaks are used to determine the sex of the donor. This XY type pattern has two peaks of different sizes and is characteristic of a male (XY); a female pattern would have two peaks of the same size.

To interpret a case sample, the analyst notes what the peak patterns are at each locus. Each locus will include the contribution from the mother (egg) and the father (sperm). If these are different, then two peaks will appear such as for TH01. If both parents have the same number of base pair repeats at a given locus, only one peak will appear, such as for D5S818 in Figure 9.10. Each sample should yield 15 separate phenotypes. Alone, a single locus is not sufficient to link a blood sample directly to a single individual, but when combined the odds of an incorrect association can be in the trillions. It is the combination of 15 STRs that makes DNA such a powerful tool for personal identification. (See Sidebar 9.3.)

**SIDEBAR 9.3. HISTORICAL NOTE: IDENTIFICATION OF WAR DEAD**

The U.S. military has unidentified remains dating back to the Civil War. The task of identifying remains of soldiers from the Civil War, World War I, World War II, the Korean War, and the Vietnam War is left to the Armed Forces DNA Identification Laboratory (AFDIL) located in Rockland, Maryland. From 1991 to 1998, the lab has worked hand in hand with the Army's Central Identification Laboratory (CILHI) in Honolulu to identify the remains of Americans unaccounted for from the Vietnam War and earlier conflicts. As of April 1998, the lab had made 93 mitochondrial DNA matches: 72 cases from Southeast Asia, 3 from Korea, 15 from World War II, and 3 from the Civil War.

In 1998, the AFDIL and CILHI gained broad public recognition when the family of Air Force 1st Lt. William Blassie suggested that his remains were contained in the Tomb of the Unknown Soldier of the Vietnam War. Defense Secretary William Cohen directed disinterment and DNA identification of the remains. It took the DNA laboratory about one month to report that DNA from the remains matched specimens provided by the Blassie family.

In 1990, with war in the Persian Gulf imminent and U.S. forces expecting many casualties, American military leaders launched a major DNA collection project and created the Department of Defense DNA Registry. Although the United States suffered relatively few casualties in the Gulf War, the Defense Department forged ahead with creation of the AFDIL and the Armed Forces Repository of Specimen Samples for the Identification of Remains, both located in Rockville, Maryland. The goal of these and affiliated organizations is to attach a name to every fallen soldier, sailor, airman, and marine. Identification is extremely important to the families. The first step was to create a database containing the DNA of all members of the military, active and reserve. Vacuum-sealed with a drying agent, these 3.6 million blood samples are now stored at minus 20°C (–4°F), ready to be matched to DNA for a soldier killed in battle, accident, or terrorism attack.

## 9.5 Mitochondrial DNA

Mitochondrial DNA is located outside the nucleus of the cell in the energy-producing organelles known as **mitochondria**. The forensic advantage of this type of DNA analysis is the great number of mitochondria per cell and DNA molecules per mitochondrion. The mitochondrial genome may be present in a cell from 100 copies to several thousand. A single hair root can be easily typed using mitochondrial analysis, as can hair shafts, bones, teeth, ancient samples of tissue, saliva, blood, semen, and any sample that is amenable to DNA sequencing. One feature of **mtDNA** inheritance is that human relatedness may be evaluated over several generations. mtDNA is maternally inherited; all members of a **maternal lineage** will share the same mtDNA sequence. Your mtDNA comes from your mother, which came from your grandmother, which came from your great grandmother, and so on. Thus, standards for comparison may be collected from any maternal relative. In general, if one compares the mutation rate of mtDNA vs. nuclear DNA, mtDNA mutates at a much higher rate, sometimes estimated at one order of magnitude or 10 times that of single copy DNA.

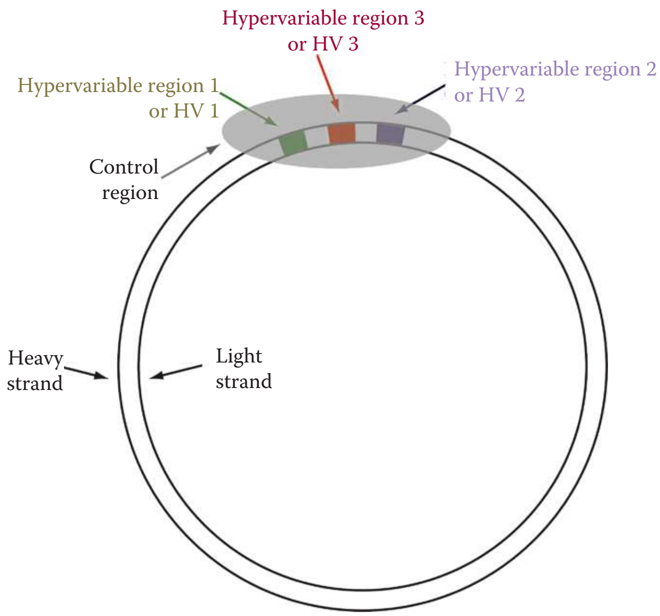



***Figure 9.11*** Mitochondrial DNA loop with hypervariable regions shown.

mtDNA is a relatively small molecule; however, some regions of the molecule are very polymorphic, such as **hypervariable regions** 1, 2, and 3 (HVI, HVII, and HVIII) (Figure 9.11). HVI and HVII are sufficiently polymorphic to allow two samples to be differentiated quite easily, but polymorphism in the third region is currently being described and will increase the power of mtDNA analysis. Full mtDNA analysis is currently being explored as a source for further polymorphisms which will increase the power of this test.

## 9.6 Y-Chromosome Short Tandem Repeats

In many sexual assault cases, it would be beneficial to be able to distinguish male DNA from female DNA. A set of STR markers associated with just the Y chromosome has recently been developed. Recall that, within our 23 pairs of chromosomes, women have an XX and men have an XY pair. Unlike conventional STRs, where two alleles per locus is the norm, a man only has one Y in his XY gender chromosome. And, because women do not have Y chromosomes as part of their genetic material, Y-STR typing is the only test that can unambiguously determine what a male has contributed to a mixed sample, like those collected as part of most rape investigations. Y-STRs are especially invaluable when very few sperm are detected in the sample, when the rapist has had a vasectomy or is sterile, when previous STRs show no Y signal at the amelogenin (gender) locus, when differential extraction is unsuccessful, when there are multiple semen donors, or when the ratio of female to male DNA is so large that the female DNA masks the male DNA. For the same reason, Y-STRs are advantageous in analyzing fingernail scrapings from a female assault victim, separating out the male skin cells from a ligature used in the strangulation of a female victim, or testing microscope slides from cold case rape kits. Y-STRs were used to confirm the identity of Saddam Hussein after his capture in a spider hole outside his hometown of Tikrit, Iraq, on December 13, 2003. Saddam's capture was verified with DNA profiling by the Armed Forces DNA Identification Laboratory (AFDIL) in Rockville, Maryland. His profile was compared to those of his sons, Uday and Qusay Hussein, who had been killed in a raid in Mosul in northern Iraq on July 22, 2003.

## Chapter Summary

DNA has changed the face of forensic science, and its use continues to develop and advance each year. The advance has been rapid, from the first case in 1987 to routine use today. The CODIS database system has become invaluable for linking crimes, identifying suspects, and investigating cold cases. The amount of sample needed for a DNA analysis has gone from a spot about the size of a dime to barely visible traces. This is largely due to the advent of PCR instrumentation and techniques. Mitochondrial DNA has proven useful in cases where nuclear DNA is not available or reliable and it is hard to see an end to new and exciting advances in DNA typing.

## 9.7 Review Material: Key Concepts and Questions

### 9.7.1 Key Terms and Concepts

Amplicons
Annealing
Base pairs (bp)
Capillary electrophoresis
Colin Pitchfork
Denaturation
DNA polymerases
Flanking region
Heterozygosity
Homozygous
Hypervariable regions
Kary Mullis
Laser-induced fluorescence (LIF)
Maternal lineage
Microsatellites
Minisatellites
Mitochondria
mtDNA
Nucleases
Nucleotides
Polymerase chain reaction (PCR)
Satellite DNA
Short tandem repeats (STRs)
Sir Alec Jeffreys
Tetramers
Variable number tandem repeats (VNTRs)

### 9.7.2 Review Questions

1. Where in the cell is DNA located?
2. Name three types of human cells that contain DNA.
3. What was the contribution of Watson and Crick to the understanding of DNA?
4. What is the purpose of the Combined DNA Index System (CODIS)?
5. Why is polymerase chain reaction (PCR) important in DNA analysis?
6. Where is mitochondrial DNA found in the body?
7. Describe the process known as PCR or polymerase chain reaction.
8. Who was the first scientist to use RFLP in a forensic case?
   a. Colin Pitchfork
   b. Tommie Lee Andrews

   c. Alec Jeffreys
   d. Joseph Castro
   e. O. J. Simpson
9. Which of the following is a class of repetitive DNA?
   a. Structural genes
   b. Microsatellites
   c. Operator genes
   d. Homologous genes
   e. siRNA
10. Which of the following is not a step in polymerase chain reaction?
   a. Denaturation
   b. Lysis
   c. Polymerization
   d. Annealing
   e. Translation

## 9.8 References and Further Reading

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# Section IV Summary

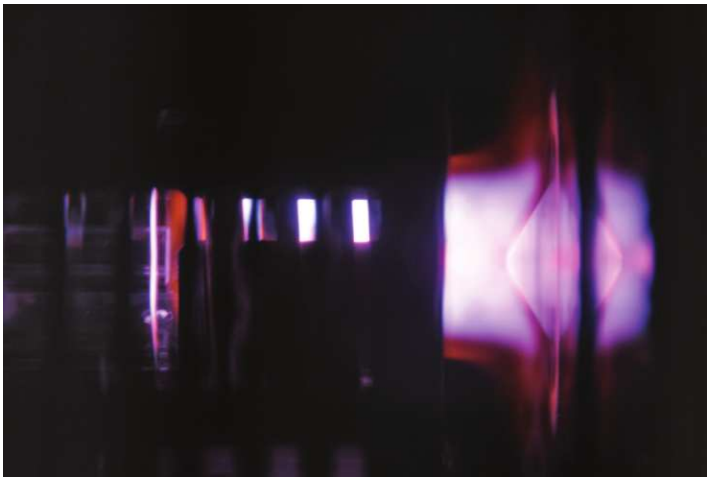
No forensic discipline has seen such rapid change in such a short time as forensic biology. Indeed, in the 1980s, the term "forensic biologist" was rarely if ever used. Analysts that tested blood were serologists. Now serologists are a rare sight in forensic laboratories. The science of DNA has also influenced forensic science more broadly and is considered by many to be a model of excellent forensic practice in which controls are clear and results are reported along with a probability. This type of approach is becoming increasingly important in other types of pattern evidence—construction of databases and calculation of probabilities. We will see several examples in the sections to come.

## Integrative Questions

1. Suppose that you had a sample consisting of only red blood cells. What presumptive and genetic tests could you perform? What could not be done and why?
2. When serologists typed blood, they usually performed a species test first. With DNA typing, this is no longer necessary. Why?
3. Is there any conceivable way that identical twins might have a minor difference in STR types? How or why? Do you think this could be a problem?
4. The CODIS database uses 13 loci, but some typing kits allow for more than 13. How could results at these loci be useful if not in the database?
5. If you ever needed a blood transfusion, the medical staff treating you must know your ABO and Rh bloodtype. Why don't they need to know your PGM type? Your DNA "type"?
6. Some labs still use serology. Why and how could it be useful?
7. Could DNA be considered to be a type of pattern evidence?

# SECTION V

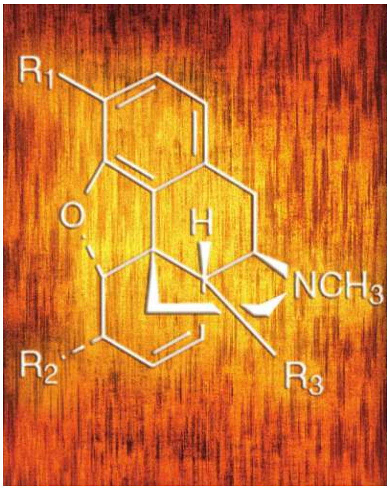
# Forensic Chemistry



## Section Overview

Forensic chemistry, much like forensic biology, encompasses more than one type of evidence. The two that are probably most familiar to the reader are the analysis of drugs as physical evidence (seized drug analysis) and the analysis of drugs and poisons that are taken by or given to people. This is forensic toxicology, and we will begin the section here. Another area that can be classified as forensic chemistry is the investigation of fires (arson) and explosives. This can also include some of the testing done in firearm analysis (Chapter 14). The unifying feature is the chemistry of combustion—fires most obviously, but guns function based on the combustion of gunpowder, and explosives are differentiated from combustion based on the speed of the reaction. Many aspects of trace evidence (Chapter 16) and questioned documents (Chapter 17) also incorporate forensic chemistry. Modern forensic chemistry relies on many types of chemical analyses, increasingly using analytical instrumentation. Fortunately, forensic chemists can usually use the same instruments for many different types of tests.

# 10
# Forensic Toxicology




## Chapter Overview

Two types of forensic scientists work with drugs and poisons: toxicologists and seized drug analysts. Both use many of the same analytical tools, but their task differs significantly. The primary job of forensic toxicologists is the analysis of biological samples such as blood and tissue for the presence of drugs, poisons, and their metabolites. Seized drug analysts work with physical evidence such as pills and powders and are charged with identifying illegal drugs. Toxicologists often work in concert with medical examiner's offices and assist in determining the manner and mechanism of deaths, and we will begin our exploration of drug analyses here. We will spend a good deal of time talking about chemical instrumentation, especially those instruments that are used in other areas of forensic chemistry.

# Chapter 10
# Forensic Toxicology*

*John Joseph Fenton and Suzanne Bell*

## Chapter Outline



## 10.1 Drugs and Poisons as Biological Evidence

**Toxicology** is the study of poisons; therefore, forensic toxicology is an examination of all aspects of toxicity that may have legal implications. (For a discussion of career preparation for this field, see Sidebar 10.1.) This is a functional definition that allows us to distinguish forensic toxicology from other sub-specializations of toxicology; for example, occupational toxicology deals with chemical hazards in the

* This chapter is based in part on Chapter 5, "Forensic Toxicology," by John Joseph Fenton, as published in the third edition of this text.

**SIDEBAR 10.1. CAREER PREPARATION AND EXPECTATIONS**

In general, forensic toxicology offers two career tracks. The first is for laboratory analysis of samples such as blood (for blood alcohol, drugs, etc.), urine, and other biological materials. These types of jobs are based in a laboratory, and the bulk of an analyst's time is spent analyzing samples and reporting results. This type of position requires a minimum of a bachelor's degree in a natural science, often chemistry. The other career track in forensic toxicology leads to jobs in which the toxicologists interprets results and offers opinions such as the degree of intoxication or cause of death. These toxicologists may or may not do the actual analyses. For this kind of position, a doctorate is required in chemistry, biochemistry, pharmaceutical science, medicinal chemistry, or a closely related discipline. A good place to begin exploring forensic toxicology is the website for the Society of Forensic Toxicologists (SOFT, http://www.soft-tox.org/). You might also want to explore the career information page at the American Academy of Forensic Sciences website (AAFS, http://www.aafs.org/choosing-career). Forensic toxicologists may work in private laboratories or in government forensic laboratories. Other opportunities exist in antidoping laboratories, animal performance labs, workplace testing labs, and in hospital and clinical settings.

workplace, and environmental toxicology focuses on toxic chemicals often of human origin and present in the environment. In the forensic sphere, procedures and testing methods may be similar to those of other areas of toxicology, but the legal ramifications of such findings are what make forensic toxicology unique.

## 10.2 Applications of Forensic Toxicology

Forensic toxicology is employed today primarily in two general areas. The first is **postmortem drug testing**. This consists of death investigation with a goal of establishing whether drugs were the cause or a contributing factor in death. There are many fatalities due to accidental or deliberate drug overdose. A small percent of such deaths are homicides. The task of the forensic pathologist is to explain what caused each death that comes under his or her jurisdiction and to determine the manner of death—that is, whether it was accidental, suicidal, or homicidal. In the case of drug-related deaths, the forensic pathologist is assisted by the forensic toxicologist, who does comprehensive analyses of a wide variety of toxins from a large variety of tissue sources. The ability of forensic investigators to find poisons in human remains is a major factor in the dramatic decline in poisoning cases noted over the past 150 years.

A second major area of forensic toxicology is **workplace drug testing** (see Case Study 10.1). This consists of testing **biofluids**, primarily urine and blood, from employees or job applicants for the possible presence of drugs. The law usually allows random (unscheduled) drug testing for employees only if they have specific occupations, such as customs agents and police officers, among others. In these occupations, the law usually places the public safety above the employee's right to privacy. Employees may also be ordered to provide specimens for drug testing for cause, that is, if they appear to be impaired at work as a result of abusive use of alcohol or other drug.

### CASE STUDY 10.1: WRONGFULLY ACCUSED?

A 41-year-old male applied for a position as an accountant with a large, multinational firm. He was provisionally hired, provided that he pass a preemployment drug screen. Three days later he was informed that he had failed the drug test because of the presence of methamphetamine in his urine. The offer of employment was withdrawn. The applicant vigorously denied use of any drug of abuse. His friends attested to his good character, but neither his denials nor his friends' testimonials reversed the decision of the employer. Eventually, the applicant hired an attorney and brought suit against the laboratory and the company. Is a laboratory error possible? If the methamphetamine finding was incorrect, how could such an error be avoided? What aspects of the subject's health history should be considered in interpreting the drug test results?

The man had suffered from a severe head cold two days prior to the drug test, and he had treated his symptoms with a Vicks® inhaler, which permitted him to breathe more easily. At the time of specimen collection for the drug test, he was asked whether he had taken any medications. He did not mention the inhaler because he assumed that the use of an over-the-counter product was irrelevant. The laboratory found a positive result for amphetamine compounds in its screening test. Gas chromatography–mass spectrometry (GC-MS) confirmed a positive result for methamphetamine. The active agent in the Vicks® inhaler is L-methamphetamine, an optical isomer of D-methamphetamine. The inhaler ingredient is a decongestant, whereas D-methamphetamine is primarily used in an abusive manner. The compounds are so similar they are not differentiated by the customary method for analyzing methamphetamine.

During the discovery phase of the case, the litigant acknowledged that he failed to state that he used the inhaler. The laboratory admitted that its method of analysis could not distinguish between the two drugs. The case was dropped and the applicant was reoffered the position. This suit could have been avoided by a review of the entire case by a medical review officer or by testing of all positives by a more specific GC-MS method. These steps are currently employed by laboratories certified by the National Laboratory Certification Program.

Workplace drug testing is concerned primarily with drugs of abuse. Medical examiner laboratories have a wider mission. They try to establish the cause of death and typically examine blood and other tissues for drugs of abuse and also for other potentially lethal pharmaceuticals and environmental toxins.

It is important to recall that abusable substances often have legitimate medicinal applications. Consequently, you should bear in mind that many of the compounds cited below are used by persons who derive medical benefit from them. Despite their chronic use of such substances, many of these persons never use them in an abusive manner. From this perspective, it would be better to call these materials "drugs subject to abuse." We will learn how drugs are defined as illegal in the next chapter.

## 10.3 Drugs in the Body

Seized drug analysts work with drugs as physical evidence. Toxicologists work with drugs (or poisons) after they are ingested into the body, which creates increased complexity in terms of samples, their analysis, and interpretation of the data produced. We can track drugs in the body in a general sense by using a framework of **ADME**. This is an abbreviation for the stages that describe how a drug moves through the body: absorption, distribution, metabolism, and excretion. The process can be illustrated with a simplified example. Suppose you have minor dental surgery, such as removal of wisdom teeth. The doctor will likely prescribe a strong pain killer that contains a drug such as codeine. To relieve pain, you would take the pills; this is referred to as oral ingestion of a substance. Next, the tablet would reach your digestive tract and the active ingredients would pass out of the gastrointestinal tract and into your bloodstream. Once in the bloodstream, the drug circulates through the body and to the point of action. This process is distribution, and it takes time; it may take half an hour for you to feel relief of the pain in this example.

Drugs are metabolized primarily in the liver, so as the codeine passes through this organ, it will be metabolized or altered in some way, usually in such a way as to make the drug more soluble in water. As the codeine, which is the molecule that acts to relieve pain, is metabolized, the effect of the drug wears off, and eventually you will need to take more to take care of the pain. Metabolites of the drug are then eliminated primarily through the urine, which may also contain some of the unchanged parent drug as well as the metabolites.

Now think of this in toxicological terms. Suppose blood and urine samples were collected from you about an hour after you took the codeine. A toxicologist has two sample matrices (blood and urine) to work with, and the concentration of drug in the blood relative to that in the urine can provide important information about when you took the drug. In addition, the urine and the blood may have metabolites as well, also in different concentrations. All of this provides the toxicologist with a rich source of information that can be used to estimate when you took your pills and how much you took. Thus, a forensic toxicologist needs to know about samples and how to analyze them, how drugs move through the body, how drugs are metabolized, and finally how to pull all of this information together to answer whatever question arises. Examples include “Was this person intoxicated when this sample was taken?” (as in a driving under the influence case) or “Did taking this drug or drug mixture cause this person to die or contribute to their death?” (as in a postmortem study). Table 10.1 summarizes the types of samples that a forensic toxicologist usually works with, depending on the specific type of case.

## 10.4 Drug and Poison Classes

We will spend a fair amount of time talking about drug classes as this information applies to both this chapter and Chapter 11, where we will discuss seized drug analysis.

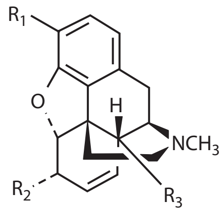
**TABLE 10.1**
**Most Common Types of Toxicological Samples**

| Type of Sample | Notes |
|---|---|
| Blood | Because the concentration of toxin present in blood often correlates more closely with lethal outcome than concentrations in other specimens, blood is the most important specimen in postmortem toxicology. Blood is also preferred to establish driving under the influence (**DUI**). |
| Urine | Urine is preferred for workplace testing and sports testing; it does not require any invasive sampling such as drawing blood. A potential problem with urine is that the correlation between the drug concentration in the urine and drug effects is usually poor. |
| Gastric contents (stomach contents) | Gastric contents may be beneficial in the case of the sudden death of a person who has large quantities of a lethal agent in his stomach. If the manner of death is suicide, large amounts of drugs in the stomach may help to establish this. |
| **Vitreous humor** | The fluid found in the eyeball is resistant to postmortem decay; it is used only in postmortem examinations. |
| Bile and liver | Bile and liver are likely to contain significant quantities of most drugs and may, on occasion, permit identification of an agent that caused death even when that substance cannot be found in the blood. Bile drains from the liver and is very rich in certain types of drugs, such as opiates. |
| Breath | A relationship exists between alcohol in the bloodstream and alcohol in the lung such that, on average, the concentration of blood alcohol is about 2100 times greater than the concentration of breath alcohol. For this reason, one can measure the breath alcohol and infer the corresponding alcohol concentration in the bloodstream. |

### *10.4.1 Opiates*

**Opiates** constitute a large class of drugs distinguished by their ability to cause profound euphoria as well as to relieve pain. Codeine, which we just discussed, is an example of an opiate. Many possess high potency as pain relievers and are derived from or related to morphine, which comes from the opium poppy, a plant that grows in copious quantities in Southeast Asia and several other areas of the world. Heroin is easily prepared from morphine and has the advantage of being less polar (more fat soluble) than morphine. As a result, heroin readily enters the central nervous system. The great pharmaceutical potential of morphine has resulted in a research effort to generate even better analgesics (pain relievers) that are less addictive. Only modest success has been achieved, and this has led to production of semisynthetic and fully synthetic analogs of morphine (Figure 10.1).

Semisynthetic opiates are those made by a simple modification of the morphine or codeine molecule. These include hydromorphone, hydrocodone, oxymorphone, and oxycodone. OxyContin® is a sustained form of oxycodone that has caused many deaths. It was designed to be taken orally and allow patients who suffer from cancer and related pain to experience long-term relief. Fentanyl (see Case Study 10.2) is another example of a synthetic opiate. Drug abusers, however, discovered that these tablets could be dissolved and then administered by injection to produce extreme euphoria. Many fatal overdoses of opiates have resulted. Opiates are classified as **depressants**. Accordingly, they produce, in addition to the initial euphoria, reduced muscle activity, depressed respiration and heartbeat, and an inclination to sleep. In overdose, they cause death, usually by paralysis of the respiratory center.




| | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|
| Hydrocodone | $OCH_3$ | =O | —H |
| Hydromorphone | OH | =O | —H |
| Oxycodone | $OCH_3$ | =O | —OH |
| Oxymorphone | OH | =O | —OH |
| Heroin | $OCOCH_3$ | $OCOCH_3$ | —H |

***Figure 10.1*** Molecular structures of morphine and codeine, natural opiates, and semisynthetic opiates.

### *10.4.2 Amphetamines*

In contrast to opiates, **amphetamine** and its analogs are stimulants that create an excitatory condition characterized by elevations of heart rate, blood pressure, and respiratory rate. They are classified as **stimulants**, and their use provokes intense euphoria. Methamphetamine can be synthesized easily by clandestine laboratories starting with ephedrine. In an effort to prevent the illicit production of methamphetamine governments have recently passed legislation that limits the availability of ephedrine. Many compounds resemble amphetamine both structurally and pharmacologically. These compounds are sold by prescription or over the counter and have decongestant, anti-insomniac, and **anorexic** (appetite suppressant) actions. Because their abuse potential is less than that of amphetamine or methamphetamine and their medical benefits are significant, regulatory agencies permit their

**CASE STUDY 10.2: A MYSTERIOUS DEATH**

A 32-year-old man went fishing with friends. He suddenly collapsed and complained of dizziness and nausea. He lapsed into a coma and medical assistance was summoned. His respirations became very weak, he became cyanotic, and eventually suffered a cardiac arrest from which he could not be resuscitated. An autopsy revealed no signs of trauma or evidence of any disease condition. The case was referred to a laboratory, which found fentanyl in the blood of the decedent at a concentration of 15 ng/mL. What were the cause and manner of death? In the absence of any other findings and in view of the concentration of fentanyl found, fentanyl was ruled to be the cause of death. Concentrations greater than 12 ng/mL are regarded as sufficient to cause death. Investigation of the decedent's work history revealed that he was a known drug abuser who worked in a funeral home. He had recently handled the body of a cancer patient. Two fentanyl patches on her corpse at the time of her funeral were missing and presumed stolen by the funeral parlor worker. One known pattern of drug abuse is to extract the drug from the patches and then inject it to achieve an opiate high. The patches contain significant quantities of drugs and unintentional overdose is a very real possibility. The manner of death was ruled an accident.

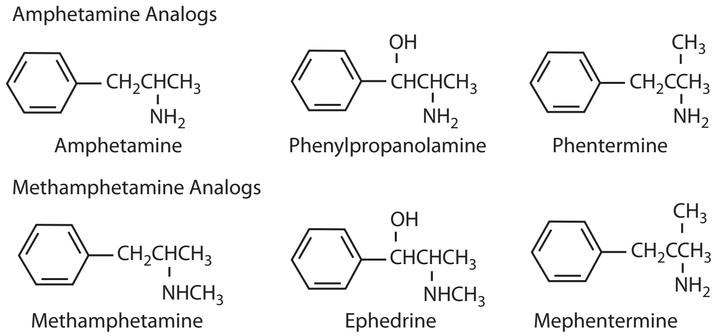



***Figure 10.2*** Amphetamine, methamphetamine, and similar medicinal agents.

sale. These compounds are numerous and include ephedrine, phenylephrine, and phenmetrazine, among others (Figure 10.2). Ephedrine and pseudoephedrine are often used as starting chemicals (**precursors**) for the clandestine synthesis of methamphetamine; as a result, many states now have controls to limit purchases of these drugs. (See Sidebar 10.2.)

### 10.4.3 Cocaine

**Cocaine** is a stimulant that resembles amphetamine in its abuse potential and pharmacological responses. Unlike amphetamine, however, cocaine is a natural product found in the coca leaf. *Erythroxylon coca*, the source of cocaine, grows in damp, mountainous regions, especially the Andes range of South America. Cocaine is extracted by a simple process from the plant material. Because cocaine is alkaline

#### SIDEBAR 10.2. CURRENT EVENTS: BATH SALTS

The last few years have seen a worrisome trend, the introduction of so-called analog drugs, those that mimic the effects of dangerous illegal drugs. These drugs are marketed as common household products and are labeled “Not for human consumption.” One example is drugs sold as bath salts. Legitimate bath salts containing salts of magnesium and calcium are added to bath water or foot baths as a soothing agent. Illicit substances sold as bath salts typically contain compounds that produce physiological responses similar to stimulants such as methamphetamine or mephedrone, shown in Figure S10.2.1. These drugs can cause hallucinations and other effects that make them exceptionally dangerous. Because many chemicals are sold as bath salts, forensic toxicologists struggle to keep up with new ones that appear.

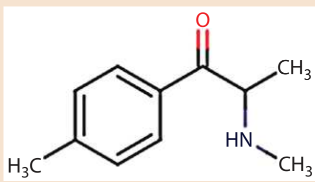



***Figure S10.2.1*** Mephedrone.

in nature and is usually extracted with hydrochloric acid, the substance produced is cocaine hydrochloride, in which the hydrochloric acid is bonded to the nitrogen atom of cocaine.

Cocaine hydrochloride may be treated with a base and extracted into an organic solvent such as ether. This additional treatment produces "free base" or "crack" cocaine. In actuality, crack cocaine and free base are chemically the same. The two names refer to slight differences in the manner of preparation. Free base and crack cocaine have much lower boiling points than cocaine hydrochloride. This difference in physical properties is very important because it makes it possible to smoke cocaine. An attempt to smoke cocaine hydrochloride would simply burn the drug. When a drug is smoked, the large surface area of the lungs is available for drug absorption. The result is that larger amounts may be absorbed per unit of time and a greater drug effect is experienced. Free base and crack cocaine were introduced into the United States during the 1980s.

Cocaine in the blood is metabolized to methylecgonine (Figure 10.3). Benzoylecgonine can also be found, but it is not the result of metabolism. For purposes of demonstrating the use of cocaine, laboratories typically analyze urine for benzoylecgonine rather than cocaine because cocaine appears in only small amounts in urine and for a brief period. Benzoylecgonine, on the other hand, appears in large quantities and is usually present for approximately three days following cocaine use.

### 10.4.4 Cannabinoids

Marijuana is a name that applies to parts of the *Cannabis sativa* plant. Many related psychoactive compounds come from this plant and the collective term **cannabinoids** is often applied to them (see Sidebar 10.3). **Tetrahydrocannabinol (THC)** is the major active agent and is present to the extent of 2 to 6% by weight in

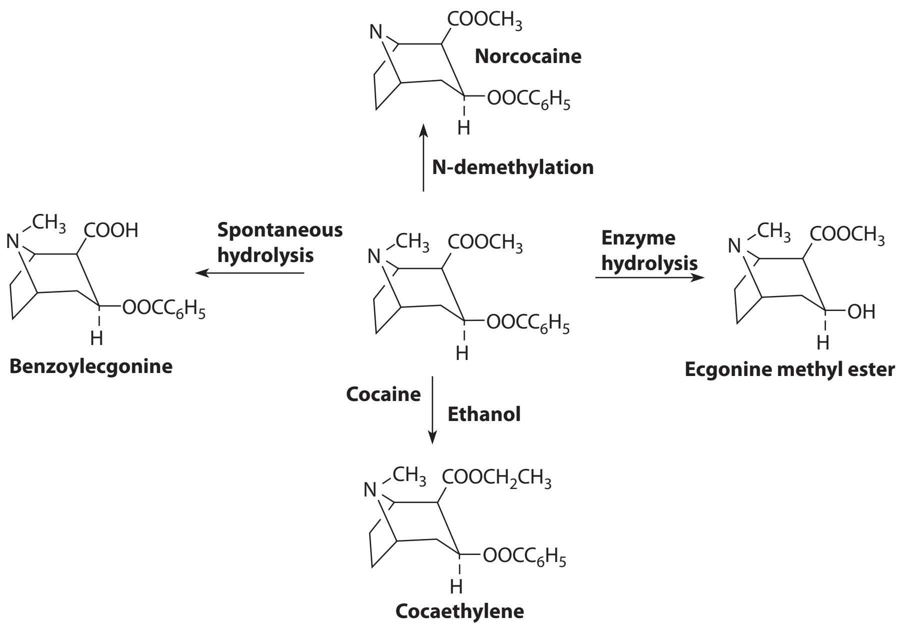



*Figure 10.3* Cocaine and metabolites formed from it in blood.

**SIDEBAR 10.3. CURRENT EVENTS: CANNABINOMIMETICS**

As we saw in the last Current Events sidebar, synthetic drugs that mimic existing illegal drugs have become a significant problem. Other examples of such drugs are the synthetic cannabinoids or cannabinomimetics ("mimics of cannabinoids") that are being sold under names such as K2 and "Spice." As with the bath salts, the products are marketed as innocuous products such as incenses and are labeled "not for human consumption." One group of cannabinoids is referred to as "JWH" compounds, named for the chemist, John W. Huffman, who manufactured the first one (JWH-018) in 1995 as part of a research project. The drug interacts with the body in similar ways to cannabinoids such as THC. The structure of the molecule is such that chemists can easily make slight changes to the molecule while retaining the cannabinoid-like activity. Because of this, new cannabinoids appear frequently, often long before toxicologists have seen them, studied them, and learned how to detect them.

cannabis (Figure 10.4). An oily extract of the plant, hashish, has much higher THC content (12%) and accordingly produces a greater psychoactive response when used. Most marijuana users smoke hand-rolled cigarettes that contain about 75 milligrams of THC. This has a bioavailability of only 2 to 20%, but it is rapidly absorbed into the blood, reaching a peak concentration around 10 to 20 minutes later. This produces a drug state that typically lasts about 2 hours. The marijuana drug state is characterized by euphoria, perceptive alterations, and memory impairment. Mood swings and hallucinations are possible with moderate intoxication, while heavy usage may provoke delusions and paranoia. THC, the active agent in marijuana, is metabolized to 11-OH-THC (11-hydroxy-tetrahydrocannabinoic acid), also an active compound. Further metabolic transformation leads to 9-carboxy-THC, the major urinary metabolite and an inactive compound. Laboratories measure THC in blood as the best index of drug-related impairment. To demonstrate drug use, however, the best test is urinary measurement of 9-carboxy-THC, which has been shown to be present in urine as long as two months after the discontinuation of heavy usage.

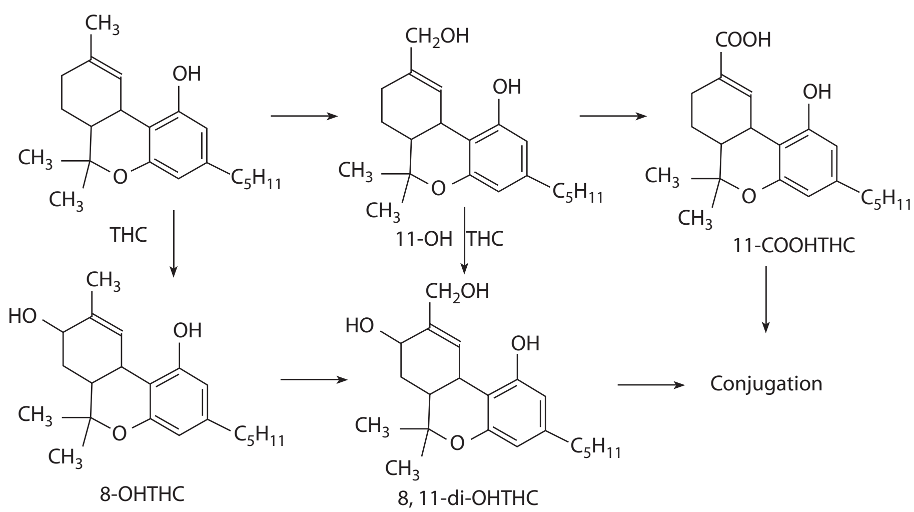



*Figure 10.4* Metabolic conversion of THC, the major psychoactive component of marijuana, to inactive metabolites.

**SIDEBAR 10.4. CURRENT EVENTS: FAMOUS DEATHS AND FORENSIC TOXICOLOGY**

Chances are that during the time you are taking this class or reading this book, at least one celebrity will have died from an overdose of a drug or, more likely, a mixture of drugs (polypharmacy). Recent examples include Michael Jackson, who died in 2009 as a result of an overdose of the anesthetic propofol. Another case involved Heath Ledger, who died in 2008 as a result of ingesting a mixture of legal prescription drugs including opiates (oxycodone and hydrocodone), diazepam (Valium®), alprazolam (Xanax®), doxylamine (a sedative and antihistamine), and temazepam (used to treat sleep problems and anxiety). Taken alone and as prescribed, these drugs are safe, but taken in combination they can become deadly. Such polypharmacy deaths are becoming more common, possibly due in part to the mistaken idea that if they are safe taken separately then they are safe taken together.

### *10.4.5 Pharmaceutical Materials*

Forensic laboratories cannot limit their search for a cause of death to abused drugs only. Many individuals die from overdoses of prescription drugs and over-the-counter medications. Such deaths are sometimes suicides but many are accidental. In the latter case, they may occur because of medicinal errors such as taking the wrong drug or the wrong dose of the right drug. On other occasions, a patient may suffer some level of organ damage from a primary medical condition and the organ injury renders him or her incapable of metabolizing a drug in the normal manner. This latter type of problem often results in a buildup of the drug in the blood to a point where the drug's concentration is greater than the lethal concentration. Most forensic toxicology laboratories are capable of postmortem identification of a wide variety of medicinal agents. Increasingly, deaths involve combinations of drugs (prescribed or illicit). This trend is sometimes referred to as **polypharmacy**. For example, a postmortem drug screen might reveal alcohol, diazepam (Valium®), and zolpidem (Ambien®). Alone, any one drug would not cause death, but in combination such drugs can become much more dangerous. (See Sidebar 10.4.)

## 10. 5 Nonmedicinal Agents

Many deaths are due to chemicals that are not medicinal but are encountered in the environment or in industrial activity. The major members of this category are alcohols, cyanide, carbon monoxide, and hydrocarbons.

### *10.5.1 Alcohols*

Ethanol is beverage alcohol. Other low-molecular-weight alcohols such as methanol and isopropanol are also present in the environment or workplace and may cause human injury. Alcohols enter the membranes of nerve cells and disrupt their normal architecture. This disruption alters normal nerve-to-nerve signaling and is believed to be the major reason for the behavioral changes brought on by alcohol consumption. Alcohols sometimes are injurious because of the toxic properties of their metabolites. For example, methanol is converted into formaldehyde and formic acid principally by the liver. These two compounds are far more toxic than methanol and, indeed, treatment of methanol overdose is best accomplished by preventing the conversion of methanol into its metabolites.

Beverage alcohol enters the blood mainly from the small intestine. Within the liver, about 90% of the average dose of ethanol is converted into acetaldehyde and acetic acid. The remainder is eliminated via sweat or urine. Ninety minutes after ethanol ingestion is the approximate time that peak blood levels are reached. This figure is certainly highly variable and is based on the interaction of many factors. The **volume of distribution** equation predicts the relationship between blood concentration and alcohol dosage:

$$C_p\ (\text{g/L}) = D\ (\text{g})/[V_d\ (\text{L/kg}) \times W\ (\text{kg})]$$

where $C_p$ = blood concentration, $D$ = dose, $V_d$ = volume of distribution (0.70 in men and 0.60 in women), and $W$ = body weight in kilograms.

We could use this equation to demonstrate the general rule that one 12-ounce can of beer or one cocktail (1.5 ounces of 100-proof alcohol) raises the blood concentration of an average size individual by 0.02%. It is also true that the average rate of ethanol clearance from blood is one drink per hour. As a result, about 1.5 hours after drinking four drinks an individual is above the legal limit for driving in the United States (0.08% blood alcohol), and about 4 hours later the blood concentration of ethanol approaches zero. These approximations are very inexact because an individual's handling of alcohol depends on many factors, one of which is the person's drinking experience.

The toxicity of beverage alcohol is well known. Acute toxicity correlates fairly well with dose and blood level. Alcohol contributes to numerous disorders as a result of chronic abuse. The liver is the organ that is most vulnerable and it shows pathological response to alcohol ranging from fatty accumulation up to liver cancer. The brain may also be attacked with very significant injury including several psychosis-like syndromes.

Alcohol testing is very important in forensic toxicology. Because the law is explicit about permissible blood levels, it is difficult to obtain a conviction for driving under the influence without proof of elevated blood alcohol. Further, the test should be conducted by a respected method in a legally defensible manner with the chain of custody carefully maintained. It is preferable to use **gas chromatography (GC)** to measure blood alcohol. This instrumental system is described in detail in Section 10.6. Blood is the preferred specimen.

What concentration of blood alcohol is sufficiently elevated as to constitute a reasonable cause of death? Concentrations greater than 350 milligrams per deciliter are listed as consistent with a cause of death. Although this is generally true, it is interesting that many individuals have survived much higher concentrations. One study also showed that the average blood alcohol concentration found in persons who appeared to have died with alcohol as the only apparent cause was just 290 mg/dL.

### *10.5.2 Cyanide*

**Cyanide** is a toxic substance that is present in myriad forms in nature. The fastest acting form is the gas, hydrogen cyanide. Salts such as sodium cyanide are highly poisonous but their onset of action is somewhat slower than hydrogen cyanide gas.

Many industrial chemicals, such as acetonitrile, are metabolized to cyanide and produce the same symptoms as cyanide, although to a lesser degree. Finally, many plant materials such as amygdalin and linamarin are poisonous to humans because their ingestion leads to the production of cyanide *in vivo* (“in the body”)

Cyanide is dangerous because it binds to ferric ions in cytochrome oxidase, an enzyme in the electron transport system within the mitochondria of cells. It interrupts the electron transport cascade, the central pathway for energy generation in human biochemistry. Without the biochemical energy generated from electron transport, life is not possible. Death occurs quickly. Inhalation of large amounts of hydrogen cyanide is fatal in less than 1 minute.

Antidotes for cyanide poisoning exist and would be fairly effective were it not for the very rapid action of cyanide. Those exposed to large doses are beyond treatment because death occurs so quickly. However, the antidote can save persons exposed to smaller amounts. Cyanide antidote contains nitrite which oxidizes hemoglobin to **methemoglobin**. The latter acts as a sink for cyanide; that is, it forms **cyanomethemoglobin**, a much less toxic form of cyanide than cytochrome oxidase. Because the cyanide is bound up with methemoglobin it does not reach its customary target, cytochrome oxidase.

Forensic laboratories can test for cyanide in whole blood, and its concentration correlates well with severity of poisoning. Normal level is less than 40 ng/mL. Levels greater than 1000 ng/mL are associated with stupor. Amounts above 2500 ng/mL are usually fatal.

### *10.5.3 Carbon Monoxide*

Some studies suggest that carbon monoxide (CO) causes more deaths than any other toxic substance. This may be true, because CO is present in fires and, together with other poison gases that result from combustion, causes more fire deaths than thermal injury. Most carbonaceous materials in the world are reduced forms of carbon (carbon bonded to hydrogen). Heat converts them to oxidized forms of carbon (carbon monoxide and carbon dioxide). In the presence of adequate heat and oxygen, reduced carbon is fully converted to relatively harmless carbon dioxide. In the presence of inadequate oxygen, however, the product of carbon oxidation is CO. Faulty heaters, indoor fires, and other situations in which carbon is not fully oxidized are the usual scenarios in which high amounts of CO are produced.

Carbon monoxide is toxic for a number of reasons. It binds hemoglobin much more tightly than oxygen so the hemoglobin is unable to fulfill its normal function of transporting oxygen to tissue. CO also causes a left shift in the hemoglobin dissociation curve. This means that hemoglobin binds oxygen more tightly at any given partial pressure of oxygen. This is dangerous because the oxygen, tightly bound to hemoglobin, cannot be transferred to its intended destination—cells in need of oxygen.

Carbon monoxide testing is commonly conducted in clinical laboratories and in postmortem evaluation. Persons whose blood **carboxyhemoglobin** levels exceed 60% are at great risk of death. Lesser degrees of hemoglobin–CO binding are associated with lesser morbidity, but it is important to be cautious in interpreting carboxyhemoglobin levels in the blood because removal from the source of CO immediately starts the process of unloading CO from hemoglobin. If testing is delayed, a carboxyhemoglobin level will underestimate the degree to which a patient was exposed to CO.

## 10.6 Analytical Methods in Forensic Toxicology

The discussion that follows on the methods of testing in forensic toxicology concentrates on the chemistries of the available technologies. The same is true in seized drug analysis, and most of the tools described here are used in that area as well. One thing that toxicology has in common with many other forensic practices is a progressive approach to sample analysis in which the first test is a screening or presumptive test. We saw this approach in Chapter 8 when we discussed presumptive tests for blood. Depending on the results of this initial testing, a confirmatory test is run if needed. This double positive finding reinforces the credibility of the result. Moreover, laboratories often attempt to demonstrate a toxin not merely by two methods but also in two locations (e.g., blood and urine, blood and liver, or another combination). Using both a screen and a confirmatory method is not merely a device to guarantee accuracy. It makes sense for other reasons; for example, there is no reason to apply a complex confirmatory test to a sample that has nothing of interest in it. This two-phase approach requires that the screening method be very sensitive although not necessarily specific. The second test, the confirmatory one, must be both sensitive and specific.

### 10.6.1 Screening Tests

#### 10.6.1.1 Immunoassays

**Immunoassays** are tests in which antibodies are used, a concept we discussed in the context of forensic biology. Antibodies are employed because they enable the reagents to react only with a substance that recognizes the antibody. We discussed this topic briefly in Chapter 8, in the context of the ABO blood group system. The substances on the surface of the red blood cell are the antigens, and the antibodies to these antigens are found in the serum. For immunoassay, an antibody is prepared against an analyte such as morphine or methamphetamine. There are many immunoassay methods based on this fundamental principle of antigens binding with antibodies and many ways in which the concentration of the drug is measured. One of these methods is based on chemiluminescence, the same process that luminol is based on. Immunoassays are objective, relatively specific, capable of high sensitivity, and compatible with automation. Their major drawback is lack of 100% specificity, but this is not an insurmountable problem because immunoassay positive test results are followed by confirmatory testing. Also, because immunoassays are used only for screening, this is not a problem *per se*.

#### 10.6.1.2 Thin-Layer Chromatography

Chromatography is a means of separating chemicals. Many chromatographic methods exist. In **thin-layer chromatography** (**TLC**), the specimen is extracted into an organic solvent and spotted onto a glass plate coated with silica. The plate is placed into a tank that contains a **mobile phase** that migrates up the plate in much the same way a paper towel will draw up liquid when it is dipped in water (Figure 10.5). The solvent moves up the plate, carrying sample molecules along with it. The more the sample molecules interact with the solid silica gel on the plate, the slower these compounds move. On the other hand, compounds that do not interact much with the solid will move quickly. This is the basis of separation of the different

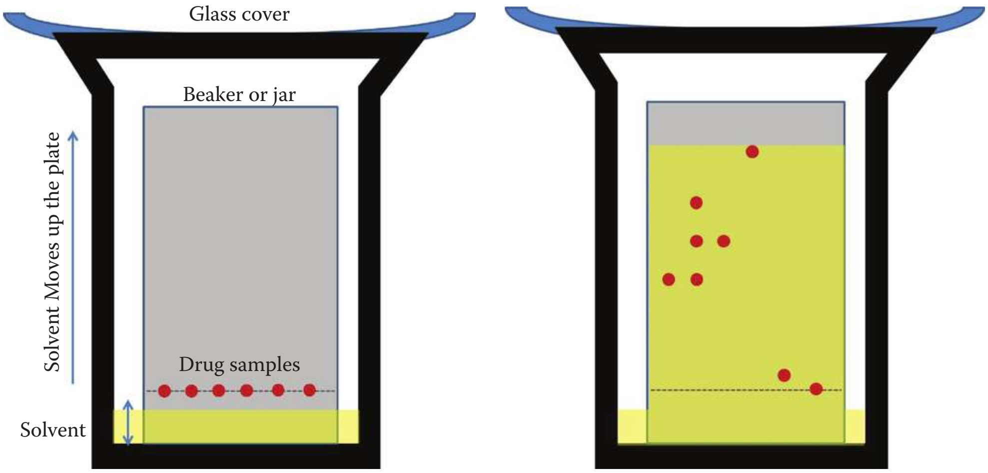



***Figure 10.5*** Depiction of the process of thin-layer chromatography (TLC).

compounds in the sample. Once the solvent has moved nearly to the top of the plate, it is removed and allowed to dry. The drugs on the plate can then be visualized in a variety of ways (Figure 10.6). Toxins are identified on the basis of the distance they migrate up the plate and on the basis of the colors they produce with various identifying reagents. TLC is an old technique but one that is still widely used in forensic chemistry. As we will see in Chapter 17, it is still a primary method for the analysis of inks. TLC is inexpensive, as it does not require any complex equipment, and as long as good standards are used it is an excellent screening technique.

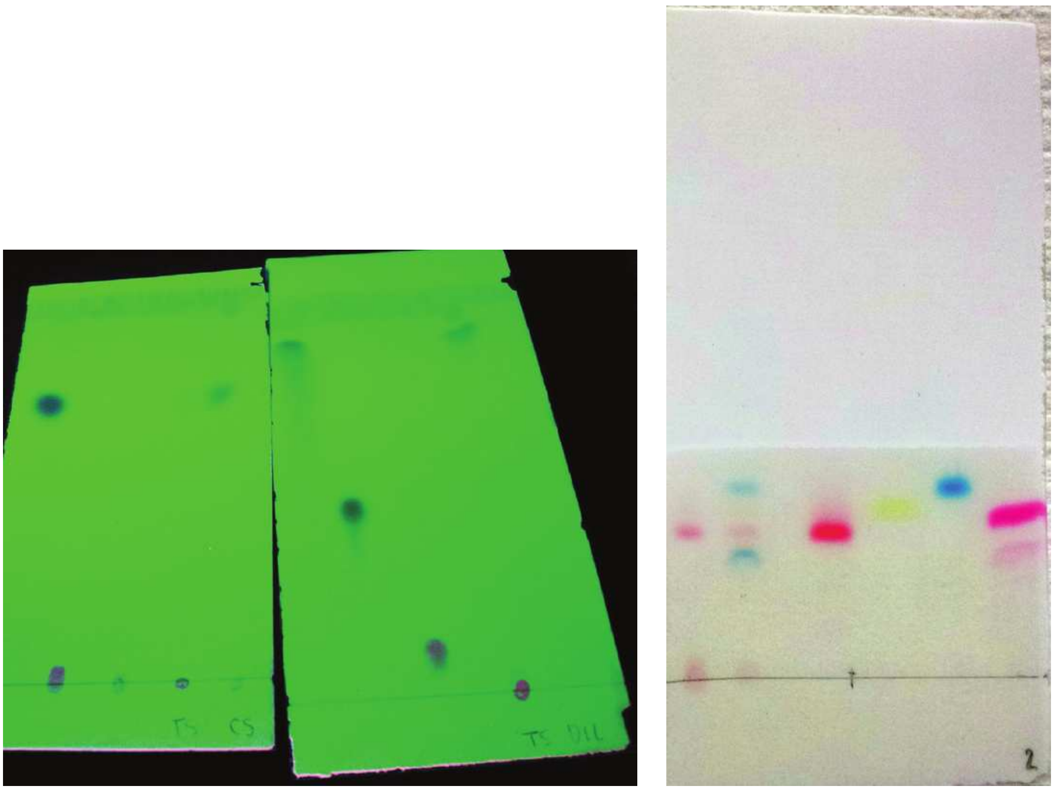


***Figure 10.6*** Examples of TLC analyses. (Right) Drugs are visualized using UV light. (Left) Dyes in inks are separated.

### 10.6.2 Confirmatory Analyses

Confirmatory analyses, as mentioned above, are sophisticated analytical methods selected to provide answers that are essentially incontrovertible. They must be sensitive and specific. If they do not meet the specificity criterion, a positive finding could be due to something other than the reported substance. Confirmatory analyses are the last analytical step. They must, therefore, be extremely reliable.

#### 10.6.2.1 Gas Chromatography–Mass Spectrometry

With samples in biological matrices such as blood, one of the most difficult parts of the analysis is separating the drug or metabolite of interest from the blood itself. This is required before the identification of the compound can be confirmed. One of the most powerful instruments used to identify compounds in forensic chemistry is the combination of gas chromatography (GC), which separates compounds from one another, with a detection system all in one instrument. GC exploits the fundamental properties common to all types of chromatography, separation based on selective partitioning of compounds between different phases of materials. We saw this with TLC where the sample molecules interacted with both the coating on the plate and with the solvent as it moved up the plate. GC works in a similar manner.

Rather than using solvent, the mobile phase in GC is an inert gas such as helium (He), hydrogen ($H_2$), or nitrogen ($N_2$). This gas is also referred to as the **carrier gas**. This gas flows over a thin solid phase that coats the walls of a long, thin tube called the *column*. The column is hollow and has a very small diameter, less than 1 millimeter. The column is also long, typically 30 meters, which means that if it was unwound it would be almost as long as a football field; however, when wound into a spiral shape, the column easily fits into a small heated oven about the size of a typical microwave oven.

The stationary phase, which is analogous to the silica coating on a TLC plate, is coated in a thin layer inside of the column, so thin that it cannot be seen without a microscope. The column is connected to the carrier gas, and the sample (after being extracted into a solvent) is introduced through a heated injector port that vaporizes the compounds in the mixture. The helium carries the molecules into the column, where they can interact (partition) with the solid phase coating the walls. The more the molecules interact with the stationary phase, the longer it takes for them to emerge from the column. The time required for a compound to emerge from the column is called the *retention time*. For this to be measured, some type of detector system has to be installed at the end of the GC column.

In most forensic applications of GC, a sample is prepared by dissolving it in a solvent, and the solution is injected into the instrument using a syringe. For example, to analyze a white powder suspected of being cocaine, a small portion is weighed out and dissolved in a solvent such as methanol. A tiny portion of the sample is then drawn up into a syringe and injected into the heated injector port of the instrument. The mobile-phase gas (carrier gas) also enters the injector port, picking up the volatilized sample and introducing it into the column where the separation process occurs. If the sample contains cocaine, it will emerge from the column at a given time (the retention time), which can be compared to the retention time of a known standard sample of cocaine. The retention time in conjunction with information obtained from the detector is used to positively identify the compound as cocaine if indeed it is present.

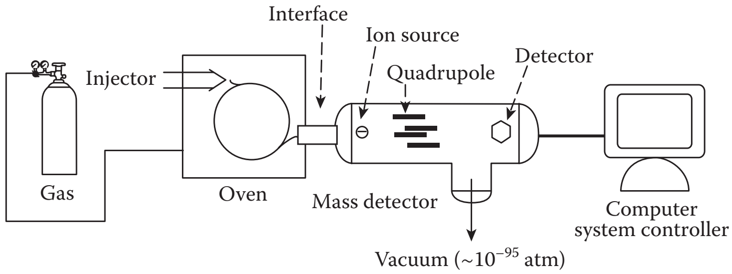



***Figure 10.7*** Schematic representation of a gas chromatography–mass spectrometry.

For absolute specificity, something more than retention time is needed. That additional assurance is provided by coupling a GC with a detector that can provide a specific identification of a substance (in most instances). Such a detector is a mass spectrometer and the combination is referred to as **GC-MS**. The most common type of mass spectrometer used in forensic chemistry is based on a quadrupole mass filter (Figure 10.7). In this type of instrument, the gas emerging from the GC column (and carrying molecules to be identified with it) is introduced into a region that is kept under vacuum. This low pressure is essential to prevent collisions between ions (charged particles) created by the instrument and atmospheric components. The sample molecule is ionized to form charged fragments ($F_1^+$, and so on) of the original molecule. The $M^+$ ion is called the “molecular ion” in that it is created by stripping a single electron away from the original compound. In organic mass spectrometry (the type that is used for the analysis of drugs, for example), this molecular ion is important because it will have the same molecular weight as the parent molecule. Smaller fragments also form that can be as small as individual atoms.

A number of different types of ionization schemes are available for mass spectrometers used for organic molecules. The most common is electron impact (EI) in which ions are created by the substance under study with electrons. Short-lived molecular fragments are formed, and they are recorded and quantified. The resulting mass spectrum is often highly unique, a virtual fingerprint of the molecule. One can, therefore, base the identification of a substance on its retention time plus its unique mass spectrum. This combination is the most perfect that can be obtained in contemporary chemical analysis. Such identifications are usually beyond question.

In some cases, mass spectra are not unique. Some molecules are resistant to fragmentation and produce fragments in low abundance that strongly resemble mass spectra of other substances. In such cases, additional analytical information is required for definitive identification.

How are substances emerging from chromatographic columns identified? This is usually left to a computer search, in which the unknown mass spectrum is matched with spectra of known toxins. The National Institute of Standards and Technology (**NIST**) has a library of over 140,000 compounds that can be searched for matches. Other libraries can also be employed, but most are smaller than the NIST library. In some circumstances, such as searching specific areas, they may have advantages over the NIST library. To obtain definitive identification, a reliable standard has to be analyzed using the same GC-MS conditions to ensure that the retention time and the mass spectrum are the same as for the sample.

#### 10.6.2.2 Liquid Chromatography–Mass Spectrometry

**Liquid chromatography–mass spectrometry (LC-MS)** is a technology in which a liquid chromatograph replaces the gas chromatograph used in GC-MS. The sample mixture under study is swept into a liquid solvent instead of a gaseous stream and is carried to a detector. Because the chemical of interest does not have to be heated for conversion into the gaseous state, this technology is compatible with virtually every known organic chemical. By contrast, it is estimated that GC-MS cannot be used with 80% of organic chemicals either because the substance being tested is **thermolabile** (breaks down at elevated temperature) or hydrophilic. In either case, the substance cannot be vaporized, which is a necessary condition for analysis by gas chromatography. LC-MS is expensive, although prices have been decreasing. Of particular interest to forensic toxicologists are instruments that combine the LC with multiple mass spectrometers in series. These instruments are referred to generically as **tandem mass spectrometers**, or $MS^n$, where $n$ represents the number of MS units in the instrument. The use of $LC\text{-}MS^n$ in forensic toxicology has grown dramatically over the past several years and in many toxicology labs is replacing GC-MS as the most used instrument. These instruments are capable of detecting very small amounts of drugs and metabolites in biological matrices, in some cases below 1 part per billion (1 ng/mL). This is roughly analogous to placing a tablespoon of sugar in an Olympic-sized swimming pool and then being able to detect it by collecting a few milliliters of the pool water.

## 10.7 Metal Analyses

Many metals are toxic to humans. Those that present the greatest danger include lead, mercury, arsenic, and cadmium. These are encountered often as environmental and occupational contaminants and occasionally as agents of homicide. Frequency of human poisonings is based on the inherent toxicity of the metal and, very importantly, on the fact that these substances are present extensively in the environment. Some of the most toxic metals (e.g., plutonium) are, fortunately, rarely encountered, and this rarity accounts for the equally rare incidence of poisonings. Other metals that are of importance to forensic toxicologists include iron, nickel, copper, zinc, bismuth, and thallium.

### 10.7.1 Colorimetric Assays

Any metal can be accurately measured by basic **colorimetric testing**. Only simple reagents and an inexpensive photometer are needed. Methods based on colorimetric endpoints were developed long ago—many in the 19th century. In particular, analyses for arsenic were discovered at that time in response to the widespread use of arsenic for homicide. The **Marsh test** (see Sidebar 10.5) was one of the first and most famous color-based tests for arsenic. Metal assays based on photometry have high detection limits. This disadvantage is partly circumvented by using a large specimen size; for example, one procedure for arsenic testing calls for a 50-milliliter sample. This is feasible for testing urine but it is not readily compatible with other biological fluids.

### 10.7.2 Inductively Coupled Plasma–Mass Spectrometry

**Inductively coupled plasma–mass spectrometry (ICP-MS)** is the best and most modern technique for metal analysis. Cost considerations and the newness of this technology prevent it from assuming complete domination of the metal testing arena. Argon atoms in an ICP-MS torch (see photograph introducing this section) are subjected to radiofrequency energy that makes them collide. This drives the temperature of the torch to greater than 6000°C. Atoms in the specimen are ionized and then directed into a mass detector where they can be separated on the basis of their masses and charges. Quantification of over 50 elements has been described, and several metals may be analyzed at one time. Very low detection limits are achieved and the linear range of detection ranges over several orders of magnitude. ICP-MS is a high-quality methodology that will undoubtedly increase in applications within the forensic sphere. The technique has limitations relating to interference. For example,

#### SIDEBAR 10.5. HISTORICAL NOTE: ARSENIC POISONING AND THE MARSH TEST

For literally thousands of years, arsenic was commonly used as a poison. Because it builds up in the system, clever poisoners could kill their victims gradually over weeks by giving small daily doses. As the arsenic built up, the victim would show symptoms such as nausea, vomiting, and diarrhea, which are common to many diseases such as cholera and dysentery. Until relatively recently (mid-20th century), these illnesses were a common cause of death, and these generic symptoms were often mistakenly associated with a natural cause. In 1836, a Scottish chemist, James Marsh, published one of the first reliable tests for arsenic in tissues. The Marsh test relied on simple chemistry and no instrumentation, and it is primitive by modern standards, but in 1836 it represented a huge breakthrough. The test is illustrated in Figure S10.5.1. Tissue or samples such as stomach contents are added to a container along with metallic zinc and an acid such as hydrochloric acid. Once heated, the arsenic, if present, is converted to a gas called arsine ($AsH_3$). The gaseous arsenic travels through the glass tube to another heated zone where the arsine breaks down into metallic arsenic which plates out and forms what was commonly called an "arsenic mirror." This was tangible physical evidence that could be shown to a jury. This test and its variants were used countless times in the decades to come to convict murderers and to eventually put an end to widespread use of metallic poisons.

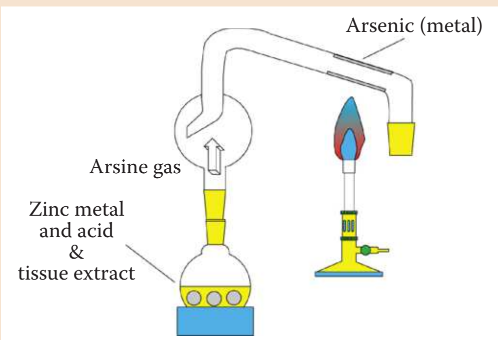



***Figure S10.5.1*** Schematic of the Marsh test method and apparatus.

the masses and charges of **isotopes** of certain metals are very similar to those of other elements. When such ambiguities occur, specific techniques are available that allow the analyst to circumvent any possible misidentification.

## 10.8 Interpreting Drug Findings

Forensic toxicologists have to be skilled in two areas. As you have seen in the previous sections, forensic toxicology relies on advanced types of chemical analysis and thus a forensic toxicologist must be skilled in analytical chemistry. Once the toxicologist has collected analytical data from different sources (blood, urine, etc.) and has identified what drugs, poisons, or metabolites are present, the toxicologist has to interpret the data, draw a conclusion, and offer an opinion. This requires a detailed knowledge of how drugs are ingested, how they are metabolized, how they may interact and interfere with each other, and what types of effects they have on a person and for how long, to name just a few considerations. Therefore, the toxicologist also has to be an expert in how drugs and poisons move through the body, which we will loosely define here as **toxicokinetics** (or **pharmacokinetics**). How a drug moves through the body in turn depends on many other factors, a few of which we will touch on here. This all ties back to ADME, which we discussed in an earlier section of this chapter.

### *10.8.1 Toxicogenomics*

The term **toxicogenomics** (or more generally **pharmacogenetics**) describes how genetic factors play a role in toxicity of an ingested drug or poison. Although this topic could cover several chapters on its own, we will touch on the basics here. For a drug to take effect, it has to be ingested and distributed to the tissues where the drug action occurs. Over time, the drug is metabolized (primarily in the liver) to forms that can be excreted in the urine. Most reactions that occur in metabolism require enzyme catalysts. As we saw in Chapter 8, some enzymes exist in more than one form across the population and are polymorphic. Recall that we talked about the phosphoglucomutase (PGM) isoenzyme system as one example. In metabolism, a different form of an enzyme (an allele) can potentially have significant impact on the efficiency of metabolism. For example, one allele might promote faster metabolism and thus faster removal of the drug from someone's system. If the drug is being taken to relieve pain, this would mean that more frequent doses would be needed to maintain the pain-relieving effect compared to a person who does not have that allele. On the other hand, if a person has an allele that slows metabolism, the drug could stay in the system much longer than would otherwise be expected. Giving this person normal doses at typical intervals could cause that person to experience toxic effects from an overdose. In toxicology, such genetic effects could play a role in toxicity, degree of intoxication, or even death. As a result, this topic is receiving more attention.

### *10.8.2 Interpreting Workplace Drug Tests*

Workplace drug testing is usually conducted for the purpose of answering one of two questions. In the context of making a hiring decision, the question is whether or not the prospective employee is a drug addict. The other situation is when the behavior of an established employee in the workplace is erratic and suggestive of

**TABLE 10.2**
**Cutoff Concentrations for Positive Specimens**

| Drug | Screening Threshold (Cutoff) (ng/mL) | Confirmation Threshold (Cutoff) (ng/mL) |
|---|---|---|
| Marijuana metabolite | 50 | 15 |
| Cocaine metabolite | 300 | 150 |
| Phencyclidine | 25 | 25 |
| Amphetamine/methamphetamine | 1000 | 500 |
| Morphine, codeine | 2000 | 2000 |

drug use. An employer will want to know if drug or alcohol use is the reason. In collecting evidence of exposure to drugs of abuse by a potential employee, it is best to examine urine for the presence of drugs or drug metabolites. In the case of an established employee, demonstrating that erratic behavior is due to abusive drug use at the workplace requires a blood test.

Table 10.2 shows the cutoff levels for declaring a urine specimen positive for certain drugs. A person whose urine contains a drug in an amount greater than the screening and confirmation limits listed is presumed to have been using the drug in question. These limits were established by the U.S. government and are imposed on testing laboratories that have met the criteria of the government's rigid certification program. The limits are much greater than zero so it appears that some degree of drug use is tolerated, but this is not the case. The nonzero limits were set because a finite quantity of a drug can result from passive exposure; for example, merely being in the presence of an individual who is smoking marijuana can cause some of the drug metabolite to be present in the urine of a non-using person. Studies show that the amounts deposited in the urine in this manner are below the 15-ng/mL cutoff established by the accrediting agency. Another factor that prevents us from setting zero as the concentration cutoff is the deteriorating precision and accuracy at extremely low concentrations of even the finest assay methods. It is reasonable, therefore, to set limits that are greater than zero despite the preference on the part of legislative agencies that no drug whatever be found in specimens.

Supporting an allegation that an employee is under the influence of a drug in the workplace is more difficult than merely demonstrating that his or her urine contains a drug of abuse. With the exception of alcohol, no specific threshold concentrations, above which everyone agrees that impairment is certain, have been determined. That is, there is no widespread consensus on what drug concentrations equal impairment. Nevertheless, finding substantial quantities of the parent drug in blood coupled with witnessed accounts of erratic behavior is often sufficient to conclude that impairment exists. Lacking a table with specific numbers, experts must testify that the amount found in blood by the laboratory is a probable explanation of the subject's behavior.

### *10.8.3 Interpreting Postmortem Test Results*

The goal of the forensic toxicologist in postmortem investigation is to collaborate with the forensic pathologist in determining the cause and manner of death. In simple terms, we infer that a death is due to a specific toxin when appropriate quantities of that toxin are found, when other findings (e.g., congestion in the lungs) are consistent with that conclusion, and when no other apparent cause of death is discovered. In addition to explaining the cause of death, the presence of a toxin may help to determine whether the death was an accident, a suicide, or a homicide.

This is a complex enterprise. For example, it is almost impossible to state that a specific death was not poison related. Negative claims infer that all possible toxins were examined. This is not possible in the real world. Even the most comprehensive analytical scheme invariably omits many exotic (but potential) toxins.

A second problem is that, for obvious reasons, controlled experiments have not been done to determine the lethal doses or lethal blood concentrations of toxins in humans. The best effort is made to get accurate values based on animal experiments and previous forensic experience. The lethal values that have been tabulated are usually reliable, but they have shortcomings. For example, some animals are much different from humans in susceptibility to the effects of specific toxins. Cats are far more sensitive than humans to benzoic acid. Rabbits are much less sensitive than humans to amanita mushrooms. Dioxin may be the strangest such example. Humans are little affected by dioxin, whereas the $\mathbf{LD_{50}}$ (the quantity that kills 50% of a population) in guinea pigs is 0.6 μg/kg; in dogs it is 200-fold greater than that amount.

A third factor that complicates the interpretation of postmortem drug levels is **postmortem redistribution**. This term refers to the concentration changes that occur after death as drugs move from one region of the body to another. For many years, scientists believed that, because blood flow stops at the time of death, the postmortem concentration of a drug would remain constant until decomposition was in an advanced stage. This is not the case, however, and specimens that are collected at different times after death usually differ to some degree in their drug concentration. A good example of this phenomenon of postmortem redistribution is found in the debate over the death penalty and lethal injection as a means of ending life. Currently, the death penalty is carried out by a series of injections. A common protocol involves the initial administration of sodium thiopental, then pancuronium bromide, and, finally, potassium chloride. Any one of these drugs is lethal in the dosages given. The thiopental induces rapid unconsciousness. Pancuronium is a muscle relaxant that causes paralysis. Finally, potassium will stop the heart from beating. This protocol was developed as a means to rapidly and painlessly cause death and eliminate objections that are raised by some opponents of the death penalty on grounds that the method is "cruel and unusual" and, therefore, unconstitutional in the United States. Some of these opponents of the death penalty studied autopsy data from persons who were executed by lethal injection. They pointed out that postmortem amounts of sodium thiopental were fairly low. It was possible, they concluded, that such persons were effectively suffocated. In other words, they were not entirely comatose because of low concentrations of thiopental and so died painfully from the next injection, the pancuronium bromide. This meant that the lethal injection protocol was a form of "cruel and unusual" punishment.

Supporters of the lethal injection method investigated these claims. They suspected that the finding of low postmortem thiopental was an artifact because 10 to 20 times a lethal dose of this drug is given. One researcher noted that the postmortem results were determined 7 to 8 hours after death, a time by which significant postmortem redistribution could have occurred. He tested one executed person by drawing blood immediately after death and also 8 hours later. Results were noteworthy. Shortly after death, blood thiopental was 29.6 mg/L whereas 8 hours later it was 9.4 mg/L. It is now recognized that sodium thiopental, being a lipophilic drug, gradually leaves the blood and enters the fat tissue after death. This finding, based on an understanding of postmortem redistribution, seems to explain the relatively low concentrations found in specimens collected in a delayed autopsy. It suggests that the drugs are having their intended effects, and the lethal injection method does not violate the constitutional protection against "cruel and unusual" punishment.

In arriving at the critical conclusion that the cause and manner of death is toxin related, toxicologists must, therefore, carefully measure all toxins with the greatest care. They must consider all associated findings for each case. They must consult data collections of lethal blood concentrations and toxin amounts in other tissues to arrive at the soundest conclusions. Finally, any effect due to postmortem redistribution must be considered. All variables must be accounted for before a final conclusion is drawn.

## Chapter Summary

Forensic toxicologists analyze a variety of biological samples and look for the presence of intoxicating compounds such as ethanol, drugs, poisons, and the metabolites of all such compounds. Often, toxicologists play the central role in death investigations when a cause of death may not be immediately obvious. Most of the analytical tools used by toxicologists are also used by seized drug analysts, so keep this material fresh in your mind as we move into the next chapter.

## 10.9 Review Material

### *10.9.1 Key Terms and Concepts*

ADME
Amphetamine
Anorexic
Biofluids
Cannabinoids
Carboxyhemoglobin
Carrier gas
Cocaine
Colorimetric testing
Contraband materials
Cyanide
Cyanomethemoglobin
Depressants
DUI
Gas chromatography (GC)
GC-MS
Immunoassays
Inductively coupled plasma–mass spectrometry (ICP-MS)
Isotopes
$LD_{50}$
Liquid chromatography–mass spectrometry (LC-MS)
Marsh test
Mass spectrometry
Methemoglobin
Mobile phase
NIST
Opiates
Pharmacogenomics
Pharmacokinetics
Polypharmacy
Postmortem redistribution
Postmortem drug testing
Precursors
Stimulants
Tandem mass spectrometry ($MS^n$)
Tetrahydrocannabinol (THC)
Thermolabile
Thin-layer chromatography (TLC)
Toxicogenomics
Toxicokinetics
Toxicology
Vitreous humor
Volume of distribution
Workplace drug testing

### 10.9.2 Review Questions

1. What are the three areas covered by forensic toxicology?
2. Name six specimen types that are often tested in forensic toxicology. Under what circumstances is each specimen preferred?
3. Name the NIDA 5. Draw a table showing the following characteristics of each drug: structure of a representative molecule, drug group, symptoms of overdose, and drug source.
4. Name several groups of medicinal drugs often involved in fatalities. What characteristics render a drug most likely to be associated with overdose deaths?
5. A 210-pound male consumes three highballs each of which was made with 2 ounces of 80-proof whiskey. What is the expected peak in his blood alcohol concentration?
6. Name three methods for drug screening and describe the advantages and disadvantages of each.
7. Contrast gas chromatography with and without a mass spectrometer detector. Describe the advantages of the latter technology.
8. What are three methods of metal analysis? Which is the optimal method and why?
9. Describe the process of interpreting drug results in the context of pre-employment drug testing. Why is drug testing for employed individuals more difficult?
10. In a published case, an elderly woman with cancer dies. Three fentanyl patches are found on her body. Discuss the investigation of her death with respect to factors that would be significant to the forensic toxicologist in arriving at the cause and manner of death.

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# 11
# Seized Drug Analysis

## Chapter Overview

As physical evidence, drugs can exist as pills, plant matter, liquids, and powders, among many other forms. Seized drug analysts are tasked with identifying illegal substances or related compounds in physical evidence. Unlike the situation in forensic toxicology, where quantitative analysis is critical, it is not common practice to quantitate the amount of given substance in evidence. Because we have discussed many of the instrumental methods and the concept of screening and confirmatory testing already, we will focus here on aspects of seized drug analysis that differ from forensic toxicological analysis.

# Chapter 11
# Seized Drug Analysis*

*Donnell R. Christian and Suzanne Bell*

## Chapter Outline



## 11.1 Drugs and the Controlled Substances Act

What is a drug? A simple way to define a drug is as a substance that when ingested causes a physiological change. Aspirin is a drug but flour is not, even though both are frequently ingested. Drugs become a law enforcement issue when they are abused or lead to criminal behavior. The concept of drugs as legal or illegal is surprisingly new; it wasn't until the 1970s that certain drugs were placed on lists of what were called *controlled substances*. In the 1960s, for example, LSD was legal.

Controlled substances are substances (usually drugs) whose possession or use is regulated by the government. Title 21 of the United States Code (21 USC) defines these as part of what is known as the **Controlled Substances Act (CSA)**. The CSA recognizes that many of the substances have a useful, legitimate medical purpose.

* This chapter is based in part on Chapter 23, "Analysis of Controlled Substances," by Donnell R. Christian, as published in the third edition of this text.

### SIDEBAR 11.1. CAREER PREPARATION AND EXPECTATIONS

To work as a seized drug analyst, an undergraduate degree in a natural science, preferably chemistry, is generally the minimum educational requirement. In this type of work, a master's degree may be of use but currently is not essential for entry-level positions. Many forensic analysts begin their career in the drug analysis section because there are lots of cases and plenty of opportunity to learn the skills essential to forensic science including the handling of evidence and testimony in court. Although there are a few private laboratories in the United States that do drug analysis, most seized drug chemists work in government laboratories. A good place to begin exploring seized drug analysis is at the career information page hosted by the American Chemical Society (www.chemistry.org or http://portal.acs.org/portal/acs/corg/content). Look for the "Careers" tab and find forensic chemistry.

Therefore, it has divided the drugs into regulated schedules based on their medical use and potential for abuse. Many state and local laws concerning the possession of controlled substances are based on these federal regulations. Others have taken the list of controlled substances and simply made their possession illegal without regard to legitimate use or abuse potential.

The CSA was passed as part of the Comprehensive Drug Abuse and Prevention Control Act in 1970. The act classifies drugs into one of five schedules (indicated with a Roman numeral) based on accepted medical use and the danger of physical and psychological dependence. Each schedule also specifies penalties and how the drug can be obtained, as well as whether a permit is necessary. Precursor chemicals used in clandestine labs are also listed. In 1984, an amendment was added as part of the Comprehensive Crime Control Act that permitted the **Drug Enforcement Administration (DEA)** to temporarily add substances to a schedule without having to wait for a more formal and lengthy procedure to take place. This allows the DEA to address newly discovered precursors and designer drugs synthesized by clandestine laboratories. In the Anti-Drug Abuse Act of 1986, a provision was added to address analog drugs synthesized by clandestine labs to act similarly to other controlled substances.

Schedule I drugs are those that have a high potential for abuse and no accepted medical applications. Heroin, LSD, and marijuana are listed on this schedule. Schedule II drugs (morphine, cocaine, and methamphetamine) are similar, but do have accepted medical uses; abuse can lead to severe addiction and dependence. Schedule III drugs have less potential for abuse and addiction and include anabolic steroids and some codeine and barbiturate preparations. Schedules IV and V reflect decreasing risk and increasing legitimate uses; drugs such as Valium® are on Schedule IV, and **over-the-counter (OTC)** cough medicines with codeine are on Schedule V. The primary task of seized drug chemists is the identification of controlled substances in physical evidence.

The analysis of controlled substances is a basic function of the forensic laboratory. The section that performs this function is known by a variety of names—drug section, narcotic analysis, and forensic chemistry are just a few. No matter what the name is, the goal is the same: to confirm the presence of a substance that is either statutorily regulated or illegal to possess. (For a discussion of career preparation for this field, see Sidebar 11.1.)

## 11.2 Scope of Seized Drug Analysis

Local laws and criminal procedures will be the driving force behind the scope of the analytical process. The laboratory's mission within its agency will also weigh heavily on determining the depth of analysis each exhibit will receive. The amount of analytical effort involved in the identification of a controlled substance for criminal prosecution purposes is significantly less than that required for intelligence gathering and investigative purposes. The only information required in a criminal prosecution is the identity and amount of controlled substance contained in an exhibit. Laboratories responsible for intelligence gathering will also identify the types and quantity of the exhibit's **cutting agents** such as sugar or starch.

The level of analytical detail required affects not only the time involved but also the type of instrumentation required. Most forensic chemistry sections can provide a complete range of analytical services, including wet chemical techniques and basic mass spectroscopy or infrared spectroscopy. As the level of detail required increases, so do the complexity and sensitivity of the instrumentation required. For example, the equipment and procedures required to confirm the presence of heroin in a street sample are far less sophisticated than those necessary to identify the region of the world in which the opium used to produce the heroin was grown. The pattern of testing, moving from screening tests to confirmatory testing, is used in seized drug analysis in the same way it is used in forensic toxicology, although some of the specific methods are different. Immunoassays are rarely used in seized drug analysis, not because they do not work but because these methods are best suited to biological matrices such as those we mentioned in the previous chapter. On the other hand, seized drug chemists rely on color-based testing and reagents much more than do forensic toxicologists.

The final issue that determines the depth of analysis is laboratory policy. The laboratory's policy is generally developed through collaboration between the laboratory's management and a peer group consisting of the examiners who perform the examinations on a daily basis. This represents a balance between the need to produce timely results that meet the applicable legal criteria while at the same time not compromising the scientific integrity of the examination.

An example of this collaboration is the need for quantitative analysis. Unless mandated by statute, the amount of a controlled substance in an exhibit is not an element of the crime. However, this information may have investigative significance and can also be used as part of an internal quality control procedure. It may not be realistic to quantitate every exhibit submitted for analysis. Therefore, laboratory and investigators work together to establish a quantitation policy that satisfies the needs of both parties. (See Sidebar 11.2 for information on designer drugs.)

## 11.3 Analytical Methods and Standards of Analysis

In October 2000, the Scientific Working Group for the Analysis of Seized Drugs (**SWGDRUG**, www.swgdrug.org) met in Vienna, Austria, to finalize its recommendations concerning the examination and identification of controlled substances. Some of these contained proposals for the minimum examination requirements for the identification of controlled substances. Although these recommendations do not

### SIDEBAR 11.2. CURRENT EVENTS: DESIGNER DRUGS

In the last chapter, we discussed two types of emerging drug threats from the perspective of forensic toxicology; however, anything that is pertinent to toxicologists is also pertinent to seized drug analysts. Physical evidence such as packets labeled “K2,” “Spice,” “bath salts,” or countless other variants are submitted to forensic laboratories every day. One of the biggest challenges with these kinds of drugs is that the compound of interest may change as illicit chemists prepare new and different variations of the base compound. JWH-018, for example, is one of dozens of possible JWH variants; because they are all so similar, they can be difficult to differentiate from each other. Making the problem worse is that forensic chemists often cannot get reliable reference standards that are essential for any forensic chemical analysis. Chemists often cannot identify new variants with 100% confidence because of this.

hold any statutory authority, they do represent the accepted analytical **standards** established by a consensus of the scientific community engaged in the analysis of drugs of abuse. Like other scientific and technical working groups, SWGDRUG continues to meet regularly and to offer guidance on suggested best practices for the drug analysis community.

The E-30 Committee of the **American Society for Testing and Materials (ASTM**, www.astm.org) reviews recommendations of the SWGDRUG analytical protocols and recommends many of them as ASTM standards. If the SWGDRUG protocols are adopted as a “guide,” they will serve as a best practices reference that does not recommend a specific course of action. If adopted as a “practice” or a “test method,” the described analytical protocols would affect how a forensic laboratory examines controlled substance exhibits.

The ASTM standards and SWGDRUG recommendations are considered the analytical benchmarks. Standard *practices* are a definitive set of instructions for performing specific operations that do not produce a test result. Standard *test methods* are definitive procedures that do produce a result. These standards should be considered when developing a laboratory’s analytical protocols. If they are not used as the foundation of the examination procedure the analytical results may not be readily accepted in court. To date, ASTM has accepted several SWGDRUG practices, including E2549-09 (Standard Practice for Validation of Seized-Drug Analytical Methods) and E2329-10 (Standard Practice for Identification of Seized Drugs). The number after the hyphen (e.g., -09, -10) indicates what year the standard was adopted.

To assist drug analysts and laboratories in developing analytical schemes for different drugs, SWGDRUG has established three categories of analytical techniques that can be used for the identification of controlled substances. The groupings are based upon the technique’s discriminating power. Table 11.1 lists the categories and associated analytical techniques. We discussed GC-MS in the last chapter, and we will discuss infrared (IR) spectroscopy in detail here.

The SWGDRUG guidelines provide recommendations for the types and minimum number of tests required to identify seized drugs. For example, if an analyst uses a validated Category A technique on a sample in addition to another Category A, B, or C technique and the results are consistent, this is considered the minimum testing necessary for identification of a drug. A combination of three different Category B and C techniques can be used if a Category A technique is unavailable.

**TABLE 11.1**
**SWGDRUG Categories**

| Category | Description |
|---|---|
| *Category C. Nonspecific Techniques* | |
| Chemical color tests | A technique that uses the colors produced by chemical reactions to provide information regarding the structure of the substance being tested |
| Fluorescence spectroscopy | An analytical technique that uses the release characteristic wavelengths of radiation following the absorption of electromagnetic radiation (fluorescence) to establish a compound's potential identity |
| Immunoassay | A laboratory technique that uses the binding between an antigen and its homologous antibody to identify and quantify the specific antigen or antibody in a sample |
| Melting point | The temperature at which a solid becomes a liquid at standard atmospheric pressure |
| Ultraviolet (UV) spectroscopy | A technique that uses the absorption of ultraviolet radiation to classify a substance |
| *Category B. Moderately Specific Techniques* | |
| Capillary electrophoresis (CE) | A separation technique using the differential movement or migration of ions by attraction or repulsion in an electric field through buffer-filled narrow-bore capillary columns as an identification tool |
| Gas chromatography (GC) | A separation technique that uses gas flowing through a coated tube to separate compounds by their size, weight, and chemical reactivity with the column coating |
| Liquid chromatography (LC) | A separation technique that uses liquid flowing through a coated tube to separate compounds by their size, weight, and chemical reactivity with the column coating |
| Microcrystalline tests | A technique that uses the microscopic crystals produced by chemical reactions to provide information regarding the identity of the substance being tested; a series of positive microcrystalline tests can be considered to be a conclusive test |
| Pharmaceutical identifiers | Comparing the physical characteristics of a commercially produced pharmaceutical product to known reference material to tentatively establish the composition of the preparation |
| Thin-layer chromatography (TLC) | A technique that uses solvents traveling through a porous medium to separate compounds by their chemical reactivity; can be documented through photographing or photocopying the developed thin-layer plate |
| *Category A. Specific Examinations* | |
| Infrared spectroscopy (IR) | A technique that uses the absorption of infrared radiation to produce a chemical fingerprint of a substance; can be used in conjunction with gas chromatography |
| Mass spectroscopy (MS) | A technique that uses molecular fragment (ion) patterns to produce a "chemical fingerprint" of a substance; can be used in conjunction with gas and liquid chromatography |
| Nuclear magnetic resonance spectroscopy (NMR) | A technique that monitors the splitting of nuclear energy levels within a molecule when it is exposed to oscillating magnetic fields |
| Raman spectroscopy | A technique that uses the inelastic scattering of light by matter to produce a chemical fingerprint of a substance |

The Category B techniques utilized must produce reviewable data. The SWGDRUG recommendations, coupled to the ASTM standards, are widely used to design, execute, and defend the methods used by laboratories to analyze seized drugs.

## 11.4 Analysis of Plant Matter

The identification of controlled substances is divided into botanical and chemical examinations. **Botanical examinations** identify physical characteristics specific to plants that are considered controlled substances. Chemical examinations use wet chemical or instrumental techniques to identify specific substances that are controlled by statute. The analytical testing sequence is represented by a simple flow chart (Figure 11.1). For each examination, a series of tests is administered to the sample. Each test is more specific than the last. At the end of the sequence the examiner is able to determine if there is a controlled substance in the sample and to identify it.

Botanical examinations are the most common examinations performed in the controlled substance section of a forensics laboratory. The plants that require botanical examinations include marijuana, peyote, mushrooms, and opium. Marijuana is by far the most common botanical examination. It is not uncommon for marijuana examinations to exceed 50% of the caseload, although case management techniques utilized by some agencies have dramatically reduced the number of marijuana examinations required. Examinations of mushrooms, peyote, and opium poppy samples are rare, but the examiner must know the physical characteristics of these plants to be able to recognize them when they are presented in case samples.

The controlled substance examiner walks a tightrope when performing botanical examinations. He or she is identifying plants and plant material, not the specific psychoactive ingredients. As a rule, by education and training the examiner is a chemist, not a biologist or a botanist. However, he or she has been trained in the

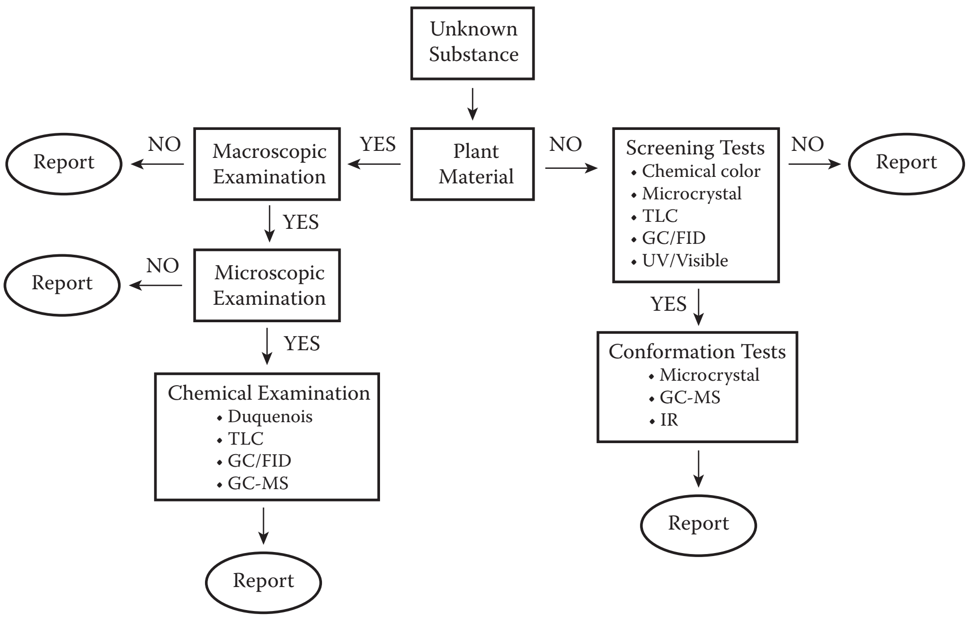


*Figure 11.1* Flow chart.

identification of specific types of plants or plant parts and can identify whether plant material is or is not marijuana, peyote, or opium. Beyond that the examiner should not render an opinion as to the identity of the substance.

### *11.4.1 Marijuana*

Marijuana was discussed briefly in the previous chapter. The term "marijuana" is the common name for the plant *Cannabis sativa* L. The identification of marijuana as physical evidence is a two-step process. The first step establishes the plant or plant material as marijuana through its physical characteristics. The second step is to establish the presence of the plant resin that contains the psychoactive components. The identification process begins with a **macroscopic examination** of the plant material to establish if the plant material has the class characteristics of marijuana. The marijuana plant (Figure 11.2) has a distinctive leaf structure with serrated edges. The plant stems have a fluted structure. These class characteristics may not be readily observed in samples of crushed plant material that has been submitted for analysis, but with experience the trained eye can recognize plant material with the macroscopic consistency of marijuana.

A microscopic examination is used to identify the individual characteristics that are unique to marijuana. This examination includes the identification of **cystolithic (bear-claw shaped) hairs** on the top surface of the leaf and finer clothing or guard hairs on the underside of the leaf. The bud material of the plant may have a red "thread" entwined in it. The identification of cannabis resin, which contains the psychoactive components (the cannabinoids described in the previous chapter), is the second phase of marijuana examination. The **Duquenois–Levine test** (Figure 11.3) is the chemical color test used to confirm the presence of cannabinoids and THC. Additional chemical tests for marijuana resin include chromatographic examination to establish the presence of specific cannabinoids. Thin-layer chromatography (TLC) has been the traditional method of choice. It separates the cannabinoids in the resin and provides a chemical color test to identify their location on the thin-layer plate. The questioned sample's pattern of colored spots is compared to a known sample of cannabis resin that is examined at the same time. It is considered a match if the patterns of the known and the questioned samples have the same sequence of colored spots.

***Figure 11.2*** Marijuana.

***Figure 11.3*** The Duquenois–Levine test.

### 11.4.2 Hashish

Contrary to common belief, **hashish** is not a potent form of marijuana. Hashish is the resin from marijuana that has been isolated from the plant material. It can be found as oil or in cake form. The oil is added to other substances and smoked. The cake can be smoked separately or added to other materials and smoked. The analysis of hashish depends upon the statute regulating its possession. The federal law does not distinguish between marijuana and hashish. Some state and local jurisdictions define hashish separately. If the hashish statutes mirror those for marijuana, a Duquenois–Levine test may be all that is required to establish the presence of cannabis resin. If the statute identifies specific compounds that must be present (e.g., THC), a confirmatory test such as mass spectrometry (MS) should be performed. Internal laboratory protocols also assist the examiner in establishing the requisite analytical scheme.

### 11.4.3 Peyote

Peyote is the common name for the small Mexican cactus *Lophophora williamsii*. The indigenous people of Mexico and the southwestern United States have used it in religious ceremonies for centuries. *Lophophora diffusa* is a rare species of peyote that is occasionally encountered. Each variety contains **mescaline** (3,4,5-trimethoxyphenethlamine), which produces hallucinogenic effects. The identification of peyote begins with a macroscopic examination of the plant material. The peyote "button" (Figure 11.4) is approximately 1 inch in diameter. It can be divided into 5 to 10 orange-like segments or it can resemble a soccer ball. Each segment contains a small white tuft of material similar to a cotton ball. Peyote does not have specific microscopic characteristics that can be used for identification purposes. The presence of the cotton-like tuft is generally used as a predecessor to the chemical examination steps. A chromatographic examination is used to confirm the identity of peyote. The examiner uses this examination to identify a pattern of **alkaloids** characteristic of peyote in a manner similar to the comparison of marijuana resin to known cannabis resin. The chromatographic pattern can also be used to identify

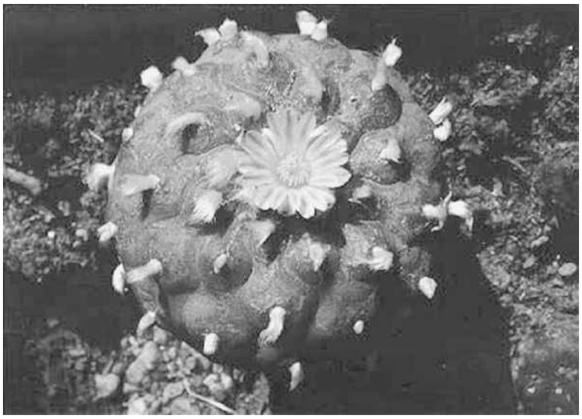

***Figure 11.4*** Peyote.

the specific peyote species. Thin-layer chromatography and gas chromatography techniques work equally well. The identification of mescaline is not an essential element of the peyote identification process; however, it should be in the chromatographic pattern that is used to identify peyote. A confirmatory test for mescaline is not required because the examiner is identifying the plant, not the psychoactive components.

### *11.4.4 Mushrooms*

The analytical approach to mushrooms is different from the approach to marijuana and peyote, as the possession of mushrooms is not illegal *per se*. The components within the mushrooms (i.e., **psilocin** and **psilocybin**) are the items that are controlled; therefore, the addition of a step to confirm the presence of psilocin or psilocybin is required. The physical identification of mushrooms that potentially contain psilocin or psilocybin is the initial step in the identification process. Over a dozen species of mushrooms contain these compounds. Figure 11.5 is a photograph of a variety of commonly encountered *Psilocybe* mushrooms. The stems of the species most commonly encountered are off-white in color with a blue-gray staining throughout. The color of the mushroom caps ranges from off-white to light brown or tan.

***Figure 11.5*** Psilocybin.

The next step in the screening process is testing for the presence of psilocin and psilocybin. These tests include chemical color tests and TLC. The preliminary identification of psilocin and psilocybin is critical in determining which confirmatory test and sample preparation technique will be used. Psilocybin is a fragile molecule. Certain sample preparation techniques convert the psilocybin into psilocin. If the preliminary identification is not done prior to the confirmatory test, the examiner cannot definitively say that the psilocin identified in the confirmatory test was originally in the sample or was a result of the conversion of psilocybin during the extraction. Therefore, it is necessary to determine the presence of the compounds prior to the confirmatory test to evaluate the results properly.

Wet chemical extraction techniques must be used for infrared (IR) spectroscopy (discussed in detail shortly) confirmation of psilocin. Two facts should be considered when using this technique. First, wet chemical extractions cannot separate psilocin from psilocybin. Second, psilocybin may be converted into psilocin during the extraction process. Therefore, if the examiner has not predetermined the presence of psilocin in the sample, it may be erroneously identified.

## 11.5 Chemical Examinations

The balance of the samples encountered by the controlled substance section require the identification of specific compounds within a mixture. The composition of the samples may vary, but the procedure remains the same. Each sample requires a screening step, an extraction or sample preparation step, and a confirmatory step. Chemical examinations can be subdivided into wet chemical and instrumental procedures. **Wet chemical procedures** are used as a screening method or for sample preparation. Instrumental procedures are used for screening or as a confirmation tool. Wet chemical procedures are used in the initial stages of the controlled substance identification process. These nonspecific tests provide a method to indicate quickly whether a controlled substance is or is not present within a sample. These procedures can be used to isolate controlled substances for confirmatory testing using instrumental techniques. Wet chemical procedures consist of chemical color tests, **microcrystalline tests**, thin-layer chromatography, and **liquid extraction** techniques. A series of these tests can be used to identify a controlled substance deductively. We discussed TLC in the last chapter; it is applied here in the same way.

### *11.5.1 Chemical Color Tests*

Chemical color tests (Figure 11.6) are chemical reactions that provide information regarding the structure of the substance being tested (see also Sidebar 11.3). Certain compounds or classes of compounds produce distinct colors when brought into contact with various chemical reagents. These simple reactions can indicate the presence of a generic molecular structure. Chemical color tests are generally conducted by transferring a small amount of the substance being tested to the well of a spot plate or into a test tube. The test reagent is added to the substance. Some tests may be conducted in a sequential fashion utilizing multiple reagents. The results of each step in the sequence are observed and noted. Positive and negative controls should be run on a regular basis to ensure the reliability of the testing reagents. A certain amount of subjectivity is involved when a color is reported. It is not uncommon for

***Figure 11.6*** Positive color tests for methamphetamine, oxycodone, and cocaine (left to right).

two people to describe the same color differently. Colors can also be influenced by the concentration of the sample, the presence of diluents and adulterants, and the age of the reagent. The length of time the reaction is observed may also influence the color reported. Color transitions and instabilities are not unusual. Allowances should be made for these differences. (See Sidebar 11.3.)

### *11.5.2 Microcrystal Tests*

Microcrystal tests (Figure 11.7) are used as a screening tool to confirm an identification made with other testing methods. They are fast and simple to perform, and can be highly specific (although whether they are specific enough to be used as a confirmatory test has been debated). In microcrystal tests, the test sample is dissolved in a solution. A test reagent either is added to the solution or is already present in the solution in which the sample is dissolved. A reaction between the compound of interest and the test reagent forms a solid compound that is not soluble in the test drop. The solid forms uniquely shaped crystals that can be observed with a microscope.

Microcrystal identification relies upon the comparison of the crystals formed by the unknown with those formed by a reference standard using the same reagent. Difficulties obtaining an exact match between the crystals of the unknown and those of the reference sample may arise. Impurities in the unknown may lead to the formation of deformed, irregular, or unusual crystals. This can be overcome by utilizing a cleanup procedure such as TLC, extractions, or particle picking prior to microcrystal analysis.

**SIDEBAR 11.3. HISTORICAL NOTE: COLORFUL HISTORY**

Color tests are used as a first step in drug analysis. The purpose of these tests is as a screening test only; if a powder sample turns purple with the Marquis reagent, for example, this indicates that the sample probably contains an opiate such as heroin or codeine. Law enforcement officers often use color tests in the field to determine if there is probable cause for further action. However, a color test alone does not provide sufficient information to make a definitive identification of a controlled substance. In most cases, additional tests as well as instrumental analysis must be used to confirm identification. This was not always the case. In the 1800s, forensic scientists were just learning how to isolate organic poisons from human tissues. The extraction of residual poison from stomach contents could be a months' long project given the tools and technology of that time. Most of that time was devoted to removing the poison from the matrix. The results were often confirmed by nothing more than a color test.

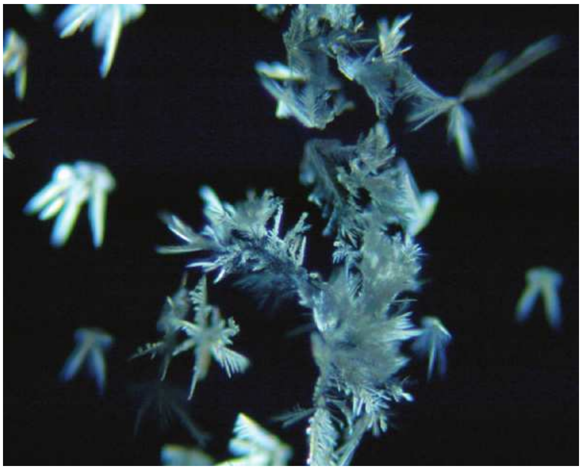

***Figure 11.7*** A microcrystal test with cocaine and gold chloride.

Other differences in crystal appearance can arise from the concentration of the solution. The crystals in highly concentrated test drops develop rapidly, resulting in a distortion of the classic crystal shapes. Concentrated test drops should be diluted to a concentration that produces classic crystal forms that are conducive to comparison and identification. Reagent age can also affect crystal development. Unknown and reference samples should be run using the same reagents, under the same conditions, and at approximately the same concentration. Polymorphism is occasionally a source of trouble. Sample concentration and reagent age can lead to the creation of different microcrystalline forms. This reemphasizes the comparative nature of microcrystal identification. The comparison should be done using the same sample concentration with the same crystal reagent.

The microscopic crystalline structures of a compound can be used to tentatively identify components within a mixture. The examiner can obtain a profile of the various components within the mixture by placing a sample into a liquid test drop in which most, if not all, of the components are insoluble (mineral oil works well for this type of analysis). The component's physical and optical characteristics are then observed under polarized light microscopy or the polarized microscope.

### *11.5.3 Extractions*

**Extractions** are used to separate the compound of interest from the rest of the sample. The type of extraction used depends upon the compound of interest and the matrix in which the compound is located. In some cases, multiple extraction techniques are necessary to separate the substance of interest from the remainder of the sample. In other instances instrumental analysis is the only way to separate compounds with similar chemical properties for confirmation. The basic types of extractions include physical extractions, dry washing, dry extractions, and liquid/liquid extractions.

- *Physical extraction*—Physical extractions are the simplest. They involve physically removing the particles of interest from the balance of the sample for later analysis. An example would be separating a mixture of sugar and wood shavings by physically separating them. Physical extraction is appropriate when the examiner observes particles of different sizes, shades, and consistency within the sample. The particles are separated from the bulk sample by the use of stereomicroscopes, tweezers, sieves, or other devices designed to physically isolate particles of different sizes.

- *Dry extraction*—A dry extraction uses a solvent to dissolve and remove the compound of interest from the sample matrix. For example, if a sample contained sugar (which is water soluble) and flour, you could add water to the solid to extract the sugar into the water while leaving the flour behind.
- *Liquid/liquid extractions*—The ability of a substance to dissolve in a liquid can change with the liquid environment. Liquid extractions utilize these solubility characteristics to separate a substance from a mixture.

During a liquid/liquid extraction, the sample is initially dissolved into a water solution in which the compound of interest is soluble. This liquid is washed with an organic liquid in which the compound of interest is not soluble, but the diluents and adulterants are. Once the organic liquid is separated, the pH of the water is changed to make the compound of interest insoluble in the water solution. An organic liquid is used to separate the purified substance from the water. Typically, the organic solvent selected will float on top of the water portion just as oil separates from vinegar. Care must be taken when selecting the acidic environment and the organic solvent used in liquid/liquid extractions.

In some instances, the compound of interest cannot be isolated because the sample matrix contains multiple drugs of the same salt type. In these instances, a combination of techniques may be necessary to isolate the component of interest. An example of a combination extraction is a TLC separation of the final extract of a liquid/liquid extraction. The silica gel around the spot corresponding to the compound of interest is physically removed from the TLC plate. A dry extraction or another liquid/liquid extraction is performed to isolate the substance from the silica gel.

## 11.6 Instrumental Examinations and IR Spectroscopy

The identification of a specific drug is accomplished using different types of analytical instruments. Gas chromatography–mass spectrometry (GC-MS), which we discussed in the last chapter, is widely used for this purpose in forensic laboratories around the world. The other standard technique is a type of spectroscopy that involves energy from the infrared region of the electromagnetic spectrum. Humans can sense IR radiation as heat. **Infrared (IR) spectroscopy** is one instrument that is used in seized drug analysis but not often in forensic toxicology. This is because IR spectroscopy is ideally suited to solid samples that are relatively pure. For this reason, IR spectroscopy has been a commonly used method for confirming the identity of a controlled substance. Traditionally, the sample was subjected to a series of screening tests to establish the compound's suspected identity. The identity of any adulterants and diluents was determined. The controlled substance was then extracted and purified. Finally, an IR spectrum was obtained. Modern technology has introduced instrumentation that can obtain an IR spectrum from a single particle or from a peak in a GC, eliminating the need for complicated procedures.

Infrared spectroscopy uses a compound's ability to absorb IR light as a means of identification. Organic compounds absorb different portions of the IR spectrum (Figure 11.8). The pattern that results from charting the absorbance and transmittance of IR light that is passed through (or reflected from) a sample is considered to

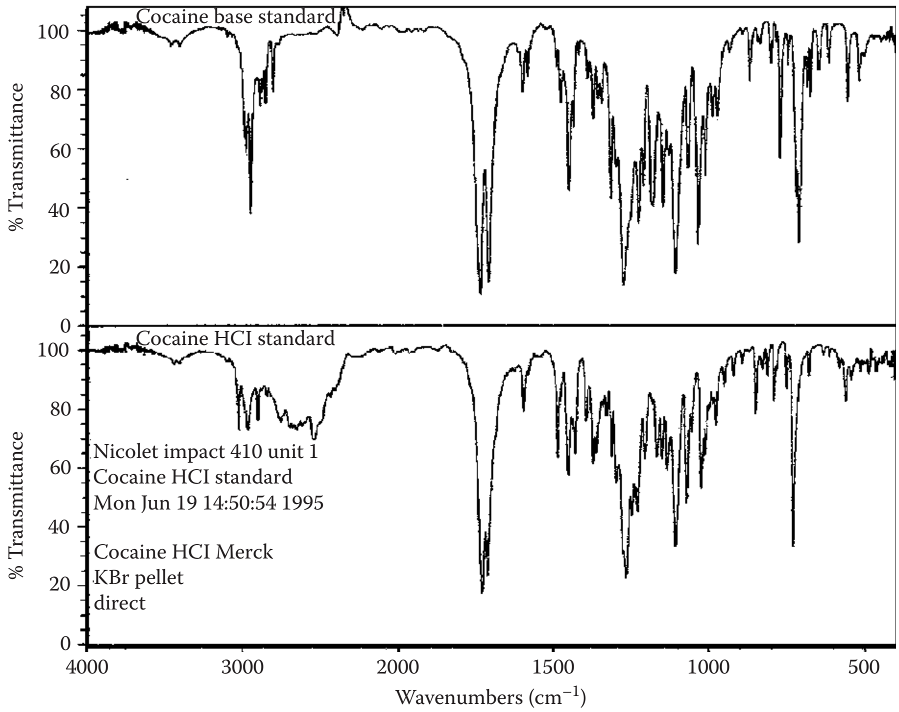


***Figure 11.8*** Infrared spectra.

be a chemical fingerprint. Infrared spectroscopy analyzes the vibrations of different parts of a molecule when it is exposed to IR light. Changing the sample method may affect the way different parts of the molecule can vibrate, which will cause shifts in the peak intensities in the resulting IR spectra. The way the compound crystallizes (or does not crystallize) within the sample matrix that is presented to the instrument will affect the resulting IR spectrum. Transmittance spectra differ from reflectance spectra. The IR spectrum of a vapor-phase sample is different from that of a liquid sample, which is different from a sample pressed into a KBr pellet or recrystallized on a salt plate.

Because of the variation of IR spectra among sampling techniques, a library of known spectra from traceable sources should be maintained for compound confirmation purposes. The various IR spectra libraries that are available should be used as a screening tool, not as a reference for confirmation. As with mass spectrometry, final confirmation is accomplished only by comparing the IR spectra of the unknown to the IR spectrum of a known reference standard. The spectra should be produced on the same instrument, under the same conditions.

## 11.7 Clandestine Drug Laboratories

**Clandestine drug laboratories** are illicit locations that manufacture controlled substances. The types and numbers of labs seized reflect national and regional trends concerning the types and amounts of illicit substances that are being manufactured, trafficked, and abused. They have been found in remote locations, in urban and suburban neighborhoods, hotels and motels, industrial complexes, and academic and industrial laboratories. They range in size from table-top setups used to produce gram quantities to large multiple-location operations that generate kilograms of final product. In each of these, toxic and explosive fumes can pose a significant threat to the health and safety of local residents.

The sophistication of clandestine labs varies widely. The investigation of clandestine labs is one of the most challenging efforts of law enforcement. The controlled substance section's involvement commences with the drafting of an affidavit used to obtain a search warrant. Their expertise is needed to process the crime scene. Forensic chemists analyze the evidence in a laboratory and render opinions in a written report or in courtroom testimony. Occasionally, they are called upon to testify on auxiliary issues concerning the clandestine lab investigation that occur after the case has been adjudicated. Examples of clandestine lab sites are shown in Figure 11.9.

Clandestine lab investigation is one of the most demanding tasks of the controlled substances section. It is a roller coaster ride of activity that requires every tool at its disposal. Traditional analytic techniques are used to develop information concerning the type and location of the clandestine lab as well as the identity of the operators. Chemists act as crime scene advisors used to identify significant physical evidence as well as potentially hazardous chemicals and situations. Their analysis is also used to corroborate investigator information and establish the identity of the final products as well as the manufacturing methods used to produce them.

The forensic chemists who deal with clandestine labs should specialize in these issues. In the realm of bookkeeping, all certified public accounts (CPAs) are accountants but not all accountants are CPAs. The same is true with forensic chemists. All clandestine lab chemists are forensic chemists, but not all forensic chemists are clandestine lab chemists. The clandestine lab chemist has additional training in clandestine manufacturing techniques as well as in inorganic analysis. This knowledge allows them to expand their analytical scheme to identify the chemicals used in the manufacturing process. Their goal is to identify the manufacturing process, not just the controlled substance final product.

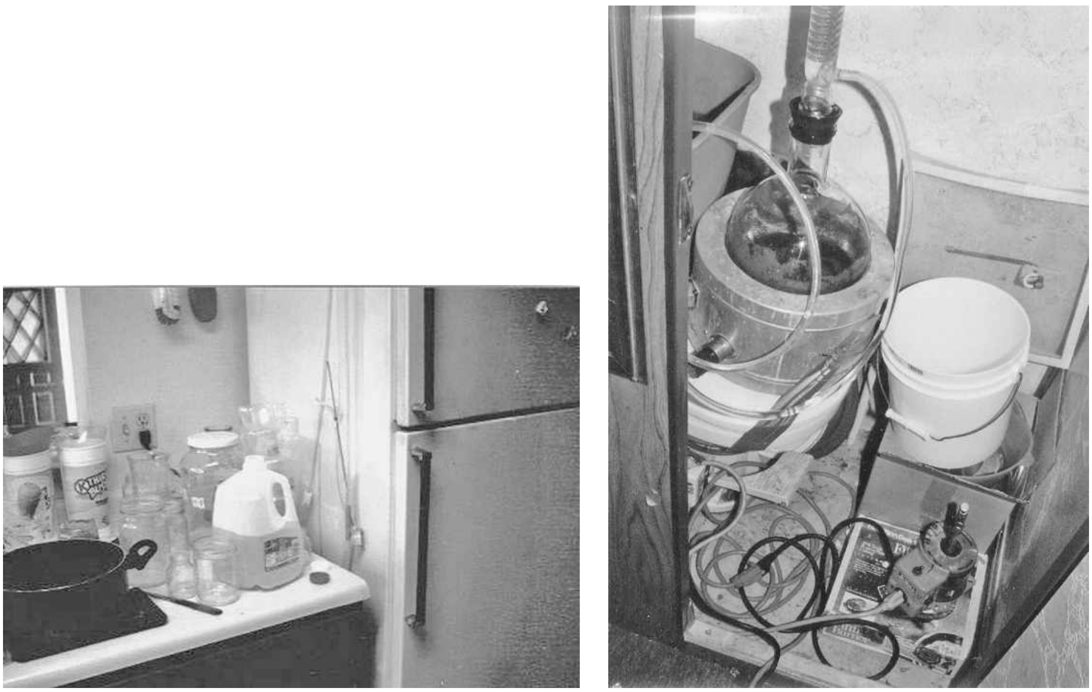

***Figure 11.9*** Clandestine lab sites.

The identification, investigation, and prosecution of a clandestine lab is a team effort. It is a collaboration of the efforts of law enforcement, forensic experts, scientists, and criminal prosecutors to present a case that definitively demonstrates how a group of items with legitimate uses are being used to manufacture an illegal controlled substance. The goal of the alliance is to establish the existence of a clandestine lab beyond a reasonable doubt.

The investigation of clandestine lab activity can be divided into five sections, all of which should involve a forensic chemist. The first section involves recognizing a clandestine lab. The second section deals with processing the clandestine lab site. The third section covers the laboratory analysis of the evidence. The fourth section encompasses generating opinions from the physical evidence. The fifth and final section covers presenting the evidence in court.

Recognition of clandestine lab activity is the first step in the process. The forensic chemist is a subject matter expert who can articulate the common elements encountered in clandestine labs. He can provide a profile of a clandestine lab operator and identify the chemical and equipment requirements, as well as the basic manufacturing techniques utilized with a given set of chemicals and equipment. He is able to describe why a clandestine lab exists and subsequently assists the investigators in securing a search warrant to proceed to the next phase of the process.

Knowing what a clandestine lab is and proving one exists are separate issues. Steps two and three of the clandestine lab investigative process deal with collecting and identifying the pieces of the clandestine lab puzzle. The information gathered from the crime scene must be evaluated. The forensic chemist acts as a technical advisor who assists investigators in processing clandestine lab sites for physical evidence. He or another chemist subsequently performs laboratory analysis on the exhibits.

Processing a clandestine lab scene is more complicated than the traditional crime scene search associated with a narcotics investigation. The site of a clandestine lab is, because of the chemicals involved, a hazardous materials (HazMat) incident and necessitates invoking different protocols for crime scene processing. There are also a number of preliminary opinions that should be made by evaluating the physical evidence observed at the scene.

A complete forensic laboratory analysis is a critical element of a clandestine lab investigation. The analysis of a reaction mixture is more complex than simply identifying the controlled substance it contains. The identification of precursor and reagent chemicals as well as reaction byproducts is necessary to establish the manufacturing method used. The identity of unique chemical components within a sample can be used as an investigative tool to connect the clandestine lab under investigation to other illegal activity. These analytical requirements require training and experience beyond that of a traditional forensic chemist who examines drug samples.

Opinions (e.g., "What does it all mean?") comprise the next phase. A large amount of information is collected during a clandestine lab investigation. The forensic chemist collates the information from various sources and creates a profile of the clandestine lab under investigation. He addresses such questions as "What type of operation existed?" "What was it making?" "How was it being made?" and "How much drug could it produce?"

All the work to this point may be useless if the information cannot be relayed effectively to a jury. In addition to providing expert testimony, the forensic chemist educates the prosecutor, deals with defense attorneys, and presents technical information to nontechnical jurors.

The use of forensic evidence is essential to the successful investigation and prosecution of a clandestine lab. The proper collection and preservation of the physical evidence followed by the complete analysis of the evidentiary samples are key elements. Their information is the cornerstone on which the forensic chemist's opinion is based. If forensic evidence is properly handled, the court will have all of the information it needs to make a fully informed decision.

## Chapter Summary

Seized drug analysis focuses on the chemical analysis of physical evidence such as plant matter, pills, and powders. SWGDRUG and ASTM are professional bodies that develop analytical procedures and protocols that laboratories can adapt for testing of such evidence. In most cases, the analysis is qualitative (i.e., identifies the controlled substance), although there are some instances where quantitative analysis is needed.

## 11.8 Review Material

### *11.8.1 Key Terms and Concepts*

Alkaloids
American Society for Testing and Materials (ASTM)
Botanical examinations
Chemical color tests
Clandestine drug laboratories
Controlled Substances Act (CSA)
Cutting agents
Cystolithic (bear-claw shaped) hair
Drug Enforcement Administration (DEA)
Duquenois–Levine test
Extractions
Hashish
Infrared (IR) spectroscopy
Liquid extraction
Macroscopic examination
Mescaline
Microcrystalline tests
Over-the-counter (OTC)
Psilocin
Psilocybin
Standards
SWGDRUG
Wet chemical procedures

### *11.8.2 Review Questions*

1. List two plants that are considered controlled substances that require a botanical examination as part of the identification process.
2. When is it necessary to confirm the identity of the controlled substance in plant material? Give an example.
3. List four wet chemical techniques that can be used in the analysis of controlled substances.
4. List two wet chemical techniques that can be used as both screening tools and sample preparation techniques.
5. List two disadvantages to wet chemical techniques.
6. List two specific and two nonspecific instrumental techniques.
7. What information should accompany instrumental data?
8. When is a library search considered a confirmation and why?

9. Which instrumental technique's spectra are most subject to variations due to sample preparation techniques? Why?
10. List three quantitation techniques in order from most specific to least specific.
11. Describe the minimum qualifications for a clandestine lab chemist.

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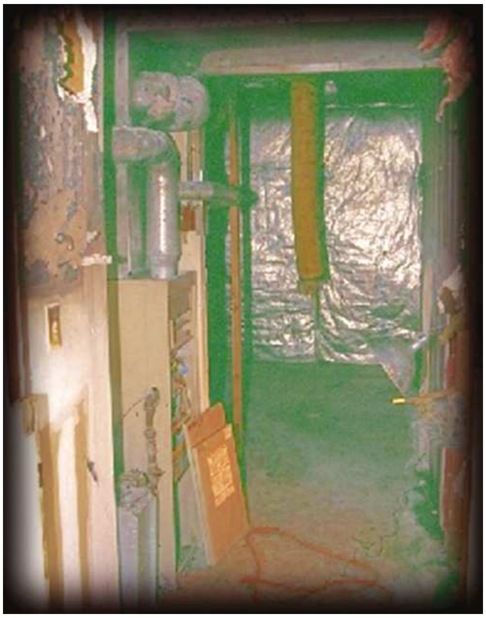
# 12

# Arson, Fire, and Explosives



## Chapter Overview

Arson and the evaluation of physical evidence recovered from fire scenes are considered part of forensic chemistry. It is not unusual for seized drug chemists to also be responsible for fire debris analysis given that the analytical techniques and instruments used are similar. Fire investigation is more closely associated with a crime scene science, but, as we saw before, the forensic link between scene and lab is indisputable. Recently, explosives have become more of a forensic as well as national security concern, so we will discuss them briefly here as well. All of the points we made during our discussion of crime scene investigation apply here. Crime scene practices that we introduced earlier would apply to a fire scene investigation as much as to the scene of a homicide. Sadly, sometimes a fire scene is also a homicide scene, as we will see later in this chapter.

# Chapter 12
# Arson, Fire, and Explosives*

*David R. Redsicker*

## Chapter Outline



## 12.1 Chemistry of Fire or Explosion

**Fire** has frequently been defined as the rapid oxidation process with the evolution of heat and light. An **explosion** is the sudden conversion of potential energy (chemical or mechanical) into kinetic energy with a production and release of gases under pressure. These may be divided into two sub-definitions: **high-order explosion** (a rapid pressure rise or high force explosion characterized by shattering the confining structure or container) and a **low-order explosion** (a slow rate of pressurization or low-force explosion characterized by a pushing or dislodging the confining structure or container). The components necessary for a fire are best described by the fire tetrahedron (a four-sided solid geometric form) made up of the four components of fuel, heat, oxygen, and uninhibited chemical chain reactions. The behavior of a fire can be affected by the addition or subtraction of any of the components during the progression or suppression of a fire. The fuel is any substance that will burn or support combustion. Fuels are found in three basic states: solid, liquid, or gaseous vapor. An example of solid fuel is wood; a liquid, gasoline; and a gaseous vapor, natural gas. (For a discussion of career preparation for this field, see Sidebar 12.1.)

* This chapter is based on Chapter 25, "Basic Fire and Explosion Investigation," by David R. Redsicker, as published in the third edition of this text.

### SIDEBAR 12.1. CAREER PREPARATION AND EXPECTATIONS

Fire investigations in the field are typically carried out by firefighters or engineers who work as consultants or for small companies. The forensic analysis of fire debris is typically conducted by a forensic analyst, and the career preparation for this is typically earning a bachelor's degree in a natural science with a significant number of courses in chemistry. There is a much greater variety of career paths for those interested in working with explosives. Several federal forensic laboratories hire analysts and chemists to work on explosives evidence; for example, visit the website for the Bureau of Alcohol, Tobacco, Firearms, and Explosives (www.atf.gov) and the website for the Federal Bureau of Investigation Laboratory Services (http://www.fbi.gov/about-us/lab). Requirements for these jobs can range from a bachelor's degree in a natural science to a doctorate, depending on the type of work involved. Military and civilian organizations within the military also employ analysts to characterize, formulate, and study explosives. Again, a bachelor's degree in a science is often the minimum requirement for entry-level work. Finally, other national laboratories, such as those in the Department of Energy, often hire chemists to work on explosives.

It should be understood that, although the fuels may exist in three different states, they can only be volatilized and consumed in the vapor state. Wood does not burn; the vapor coming off of the wood does. The burning of solid and liquid fuels takes place at the surface of the fuel in the area where the vapors have been created by heat and subsequently ignited. An oxidizing agent is required to support combustion. The most common is the oxygen in the Earth's atmosphere. Normal atmospheric air contains 21% oxygen. Typically, flaming combustion occurs above 15% oxygen in the atmosphere. A smoldering fire may continue at much lower percentages. Generally, the higher the ambient temperature, the less oxygen is required for combustion.

Obviously, oxygen is necessary for the normal combustion process. If the oxygen in the environment is limited, it is consumed during the fire process. This results in the production of carbon monoxide, which is very common at most fire scenes. Carbon monoxide asphyxiation is the primary cause of death in fatal fires. Carbon monoxide is also a fuel with an ignition temperature of 1128°F and is the likely cause of most backdrafts or smoke explosions. Fuel is matter that exists in three physical states: solid, liquid, and gas. Solids decompose with heat, vaporize, and become gases. Liquids do not burn; however, the vapors rising from the liquid surface do burn similar to wood vaporization. Gaseous fuels are those in which molecules are in rapid movement and random motion. They have no definite shape or volume and assume the shape and volume of the container. How a gas diffuses in air depends on its vapor density relative to air. The nearer this is to the vapor density of air (a value of 1.0), the greater the ability of the gas to mix with air. Various gaseous fuels have different vapor densities. Methane equals 0.6 and is lighter than air. Propane is 2.5 and is heavier than air.

When a gaseous fuel diffuses into air, the mixture may ignite or explode. The percentage of gas to air at which this occurs is the lower limit of the flammable (explosive) range of that gas. The upper limit is the percentage at which the mixture is too concentrated to ignite (e.g., natural gas range is 5 to 15%). We will discuss explosions and explosives in a bit more detail toward the end of the chapter.

Liquid fuels also assume the shape of their container. Because a liquid's boiling point indicates imminent vaporization, it is one measure of the volatility of a liquid fuel. Two other indicators are flashpoint and fire point. The **flashpoint** is the temperature at which a liquid gives off sufficient vapors to form an ignitable mixture at its surface (gasoline is –45°F and kerosene is 100°F). The **fire point** is the temperature at which a liquid produces vapors that will sustain combustion. This is generally several degrees higher than the flashpoint (e.g., gasoline is 495°F and kerosene is 110 °F). The generally accepted temperature used to distinguish **flammable liquids** from **combustible liquids** is defined as 100°F; temperatures below 100°F classify flammable liquids, and temperatures greater than 100°F classify combustible liquids.

Heat is the tetrahedron component necessary to increase the temperature of the fuel in the presence of oxygen and cause ignition. One must understand how heat is produced and transferred as it relates to a fire. Heat is the energy possessed by a material or substance due to molecular activity. There are five basic methods of heat production:

- *Chemical*—Chemically produced heat is the result of rapid oxidation. The speed of the oxidative reaction is an important factor. Rust is a product of oxidation, but a very slow one.
- *Mechanical*—Mechanical heat is the product of friction. Internal metal components of machinery can overheat due to lubricant breakdown or ball-bearing failure and cause ignition of available combustibles.
- *Electrical*—Electrical heat is the product of arcing, shorting, or other electrical malfunction. Poor wire connections, too much resistance, a loose ground, and too much current flow through an improperly sized wire are other sources of electrical heat.
- *Compressed gas*—When a gas is compressed, its molecular activity is greatly increased. Consider the operation of a diesel engine. The gaseous fuel is compressed within the cylinder, increasing its molecular activity. The heat generated by this activity eventually reaches the ignition temperature of the fuel itself. The resulting contained explosion forces the piston back to the bottom of the cylinder, and the process repeats over and over again.
- *Nuclear*—Nuclear energy is the product or splitting of atomic particles. The tremendous heat energy in a nuclear power plant produces steam to turn steam turbines. Once a fire initiates, it can only continue through a transfer of the heat by molecular activity.

Three of the most common forms of heat transfer are **conduction**, **convection**, and **radiation**:

- *Conduction* is the transfer of heat through direct contact. If you touch a hot stove, the pain you first feel is the result of conducted heat passing from the stove directly to your hand. In a structural fire, superheated pipes, steel girders, and other structural members, such as walls and floors, may conduct enough heat to initiate fires in other areas of the structure. Heat transfer by conduction is responsible for the spread of fire in almost every structure.
- *Convection* entails the transfer of heat by a circulating medium, usually air or liquid. The superheated gases evolved from a fire are lighter than air and consequently rise. As they travel and collect in the upper levels of the structure, they can and do initiate additional damage.

- *Radiation* is **radiated heat** moving in invisible waves and rising much the same as sunlight or x-rays. Radiated heat travels at the same speed as visible light (186 miles per second). It is primarily responsible for the exposure hazards that develop and exist during a fire. Radiant heat travels in a direct or straight line from the source until it strikes an object.

A chemical chain reaction is a complex series of events that must be continuously and precisely reproduced to maintain flaming combustion. Two events must occur: (1) the oxidation reaction must produce sufficient heat to maintain continued oxidation, and (2) the fuel mass must be broken down into similar compounds and liberated (vaporized) from the mass itself, and, in turn, these unburned vapors must combine with available oxygen and be continuously drawn up into the flame.

## 12.2 Behavior of Fire

There are many factors that affect the progression of fire. Initially, fuel supply, oxygen, and an available heat source are necessary. However, as the fire evolves and spreads to other combustibles or flammables in proximity, the fire progression may increase rapidly. As long as there is a sufficient supply of these three basic components, the fire will continue until either structural components of a building or fire suppression efforts change the conditions. Basically a fire extends horizontally and vertically from its **area of origin**. It follows the path of least resistance through ceilings, doorway and window openings, and stairwells as it progresses unimpeded. Other factors that may affect the progression and growth of the fire may be an environmental element (e.g., heavy winds and direction may increase the intensity of the fire as well as the path). During a fire's progression, it normally transcends four phases:

1. *Incipient*—This is the earliest phase of fire, which may last anywhere from a fraction of a second to several hours or days depending on the fuel or **ignition source**.
2. *Emergent smoldering*—In this phase, the products of combustion become increasingly pronounced. Some fires, such as smoldering mattress fires, may pass directly from this second phase to oxygen-related smoldering (fourth phase).
3. *Free burning*—During this phase of the fire, the rate and intensity of open burning increase. The intensity of the fire doubles with each 18°F (10°C) increase in temperature. Heat rapidly evolving from the original point of the fire is convected and collects at the upper areas of the structure or room. Additional heat is transferred through conduction and radiation. During this phase, a flashover may occur when the temperature reaches the ignition temperature of all of the combustible items in the room.
4. *Oxygen-regulated smoldering*—This final phase occurs when the oxygen-enriched air in the room during the third phase (free burning) is depleted.

The depletion of oxygen supply causes the flaming combustion to end, and it is replaced to a large extent with **glowing combustion**. This produces heavy, dense smoke and gases, which are forced from the room under pressure. The fire continues to smolder, and the temperatures exceed 1000°F. The resulting superheated mixture of gases requires only a fresh supply of oxygen to resume free burning at an explosive rate. This type of explosive ignition is referred to as a **backdraft**. One of the superheated gases produced by fire is carbon monoxide (CO). This odorless, colorless gas collects and mixes with oxygen to within its explosive or flammable limits, 12.5 to 74% of the atmosphere by volume. Carbon monoxide is highly flammable and has an ignition temperature of 1128°F. When the ignition occurs, the entire cloud of smoke within the area or room literally explodes or bursts into flames.

## 12.3 Origin and Cause Analysis

The methodology behind determining the origin and cause of a fire is, for the most part, the same as the guidelines for proper investigative procedures. To determine where a fire started (its origin), one must first evaluate those areas of the structure that were not damaged or were less affected by fire than the area of heaviest fire damage. Typically, the heaviest fire damage occurs at or near the area of origin. The area of origin is identified through the evaluation of **fire patterns** and physical evidence, including charring, melting, and distortion of components or items in a fire; the point of origin is the point or spot within the area where the fire initally started. To identify the point of origin, one must evaluate the effects of the fire within the area of origin to identify the most severely damaged lowest point of origin.

When the point of origin has been identified, then the cause of the fire can be determined through the careful inspection and analysis of any potential heat sources identified at or near the point of origin. Examples of points of origin are shown in Figure 12.1. The cause of a fire can usually be categorized as one of four classifications:

***Figure 12.1*** Examples of points of origin.

1. Accidental, explainable (may include negligent acts)
2. Natural, act of nature (lightning; see Case Study 12.1)
3. Incendiary, intentional act of setting a fire
4. Undetermined, cause unknown, unable to be identified

## CASE STUDY 12.1: LIGHTNING STRIKES

This case involved a residence that was equipped with a lightning protection system. It was installed by a licensed contractor specializing in the installation of this type of equipment. The fire occurred during the lightning season. The fire report as well as a follow-up weather report confirmed lightning on the date of loss. During the investigation, it was learned that the extent of fire damage was affected by the delayed response of the local fire department. The home was located in a rural area on a remote private road on top of a hill. The fire department was a volunteer organization that required a response of local fire fighters from either their homes or places of business to the fire department and ultimately to the fire scene. As a result, the home was totally destroyed.

The scene examination involved the normal origin and cause analysis with exterior scene examination as well as interior inspection of the remains of the property. During the inspection, the electrical system was identified on the west side of the residence. The point of origin was on the southwest corner of the residence approximately 75 feet from the incoming electric service. The service entrance was underground. The area of origin was a utility room that housed the water pump, water storage tank, and electric water heater. The water well system was a submersible pump located near the southwest corner of the residence. The water line fed from the well casing underground to the storage tank in the utility room. The water line was standard 5/8-inch copper. The electrical systems grounding for the incoming service to the panel was completed with stranded copper cable to the water line.

During the evaluation of fire patterns on the structural wood components (walls and remaining ceiling structure), a very low burn pattern was noted at the corner of the utility room where the water line entered through the sill plate. Upon closer inspection of the water line leading to the water storage tank, unusual scorch and arc marks were discovered spiraling around the water line and terminating at the pump pressure switch. To further evaluate this unusual evidence, the buried water line out to the well pump head was dug out and exposed. During this excavation, which was approximately 24 inches below the surface of the ground, a second grounding cable was uncovered affixed to the water line. This was traced to the corner of the building and up to the eave level where it dropped into the fire debris of the house because the roof was completely gone. Inspection of this grounding cable continued to the first lightning rod on the south end of the residence. Subsequently, it was tied into additional lightning rods that were on the residence. After completion of the excavation, it was determined that the lightning rod system had been grounded to the same water line as the grounding for the electric service in the residence.

The lightning strike to the lightning arresting equipment grounded to the water line, which continued into the residence via the copper water line to the water storage tank. As it passed through the sill plate, a smoldering fire ignited in the wall and subsequently involved the entire structure.

Determination of the cause and ultimately the responsibility for a fire involves the recognition of the degree of human intervention (factor). Almost all fires have some type of human involvement whether intentional or accidental. The degree of involvement often involves the culpability of a person or persons involved. Important questions to ask and answer are "What did they do?" "When did they do it?" "Where was the work performed?" "Why did they do the work?" "How did they do the work?" Ultimately, determination of the cause and responsibility for the fire may identify circumstances and factors that were necessary for the fire to occur (see Case Study 12.2). These circumstances and factors may be certain equipment involved in the ignition of the fire, the presence or absence of combustible or flammable material, and the circumstances of the human factor that brought the ignition source and fuel together to cause the fire. This, in turn, may bring about certain legal actions, either criminal or civil. In the criminal justice system, an individual may be charged with the intentionally starting the fire for various motives ranging from financial to revenge. Criminal charges may include arson, insurance fraud, or murder. In the civil arena, the interest is in obtaining some type of monetary compensation in the form of subrogation. Subrogation is defined as the legal action of substituting one creditor for another, as when an insurance company seeks to recover the costs it paid out due to a manufacturer's defective product or negligence on the part of a service provider.

One other area of concern and consideration before we get into the actual physical examination of the fire scene is the topic of **spoliation**, which is the intentional or negligent destruction or alteration of evidence. The physical examination of the fire scene is approached in the systematic method addressed in the introduction. With this in mind, the investigation takes on an increasingly focused analysis commencing with the exterior of the structure and then the interior, determining the room of origin, the point of origin, and the cause. The reconstruction and examination of the fire scene can be seriously impeded by indiscriminate or haphazard handling of the routine firefighting operation known as *overhaul*. This involves the inspection of and, when necessary, the movement or removal of debris in an effort to discover concealed embers or flames that might rekindle the fire. If circumstances permit, the room of origin should not be overhauled before an investigator is on the scene; otherwise, evidence may be destroyed.

The purpose of the exterior examination is to document the fire conditions and patterns, which help to document the fire spread and direction of fire progression. Also included in this examination is documentation of the utilities, including electric, gas, or other fuel service, into the structure. The purpose of this evaluation is to either eliminate or document the involvement of the utilities in the cause of the fire. During the next phase of the investigation, the examination of the interior of the structure progresses from the least amount of fire damage to the heaviest fire damage, which ultimately identifies the area or areas of fire origin. Remember that more than one area or point of origin may be an indicator of an intentionally set fire (incendiary). The absence or presence of contents, the condition of the contents, and the fire spread as determined by various char, heat, and smoke patterns further help to evaluate the ultimate point of origin of the fire.

Fire safety systems should be evaluated, including smoke detectors, heat detectors, fire escapes, and fire equipment to improve fire safety and fire prevention. To this end, it is important to document the location and integrity of the fire safety systems as they relate to the fire origin and the ultimate factor in the injury or death of the occupants of the structure. Local, state, and federal fire safety codes should be reviewed and addressed in the report along with the origin and cause analysis. Once the area of fire origin has been determined, whether it is on the exterior or

## CASE STUDY 12.2: HOT WATER HEATERS AND MOTORCYCLES

The residence in question was a three-story townhouse in a complex of six identical units. This particular townhouse was occupied by a young couple. The fire occurred on a Sunday morning at around 10 a.m. The husband was an avid motorcycle enthusiast who raced on Saturdays. The motorcycle was stored in the garage of the townhouse along with his other vehicle. The garage was separated from the main living area by a fire-rated sheetrock wall on wood studs. The door leading from the garage into the entry foyer was a steel fire-rated door off of the back of the entry foyer on the same level as the utility room where the natural gas-fired water heater, furnace, and laundry area were located. The second level consisted of a kitchen, living room, dining room, and a den. The third level contained three bedrooms and a bathroom.

On the date of loss, the homeowner had been in the garage cleaning his motorcycle and decided to run down to the local store to get the newspaper. When he pulled out of the garage, he left the overhead door open. While he was away from the residence, his wife worked out on her exercise treadmill and decided to take a shower. After her shower, she entered the kitchen on the second floor, which was at the front of the residence. She was alerted to the fire by an explosion and heavy smoke conditions coming from the ground level of the residence. She ultimately evacuated the second floor level via a deck off the living room.

Upon the arrival of the fire department, they encountered heavy fire in the garage and utility room that was ultimately suppressed. The insurance carrier for the homeowner requested an independent investigation of the origin and cause of the fire. During this investigation, it was found that the motorcycle was lying on its side in the garage adjacent to the wall that separated the garage from the utility/laundry room area (Figure CS12.2.1). The fire department had already breached the wall during their fire suppression efforts. During examination and reconstruction of the scene, it was noted that, although the wall was constructed with the proper fire-rated sheetrock, there was a void at the base of the wall. The void was due to the lack of a wooden sill plate adjacent to where the motorcycle was lying (Figure CS12.2.2). The reason the sill plate was missing was because the contractor failed to use the proper length 2 × 4 wood framing and chose to use whatever piece was left over, creating a 6- to 8-inch void at the base of the wall (Figure CS12.2.3). On the opposite side of the wall in the utility/laundry room were the water heater and furnace (Figure CS12.2.4). The carpeting on the utility room floor had a burn pattern extending from the void in the wall over to the area of the water heater and furnace.

An inspection of the furnace and water heater was conducted to determine which might have been involved in ignition of this fire. It was obvious from the inverted **"V" patterns** on both sides of the wall between the garage and utility/laundry room that there had been a flammable/combustible liquid burning on the floor. This was further confirmed by the patterns on the motorcycle on the floor, particularly around the fuel tank cap, which was still in place. Closer inspection of the patterns in the utility/laundry room revealed soot patterns around the opening to the burner area of the water heater (Figure CS12.2.5). This was not present on the furnace.

*(continues)*

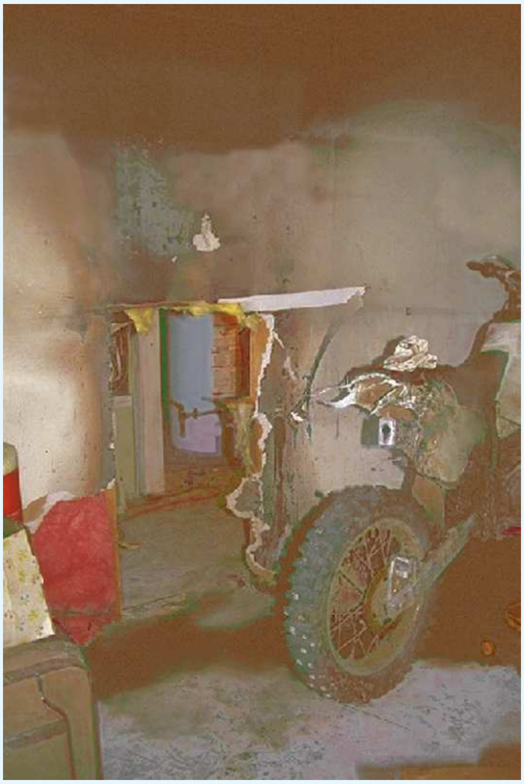


***Figure CS12.2.1*** Overall view of the point of origin from the garage side showing the location of the motorcycle in relation to the hole in the wall.

As a result of the investigation, the following facts were considered in the conclusion as to the origin and cause of the fire. The husband confirmed that the motorcycle still contained approximately 1 gallon of gasoline in the tank after he completed racing. It did not have a kickstand and was leaning up against the wall. After he left to go to the store, the garage door was left in the open position, allowing air movement into the garage from the exterior.

***Figure CS12.2.2*** Close-up view of the hole in the wall made by the fire department as viewed from the garage side.

***Figure CS12.2.3*** View of the same hole in the wall as viewed from the utility room side. Note the defect in the wall where the sill plate is missing.

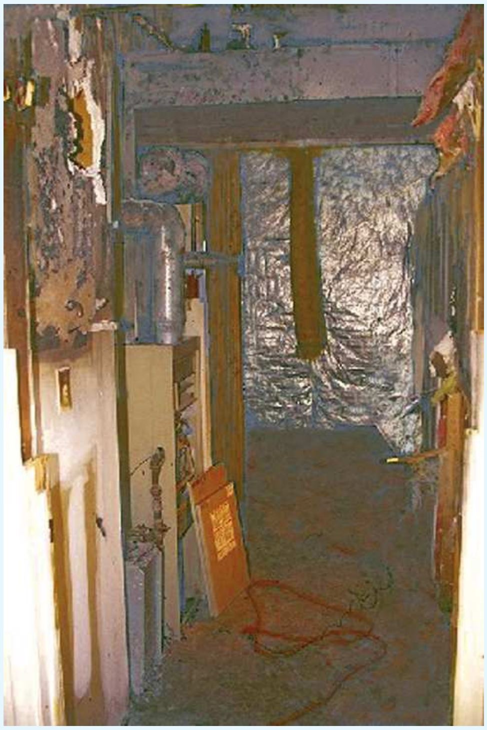


***Figure CS12.2.4*** View into the utility room showing the water heater and furnace on the left and the hole in the wall on the right.

When the bike fell over, the gas leaked from around the gas cap, which was not sealed tightly because he had been working on the bike earlier. As the liquid gas spilled from the tank, it flowed under the wall through the void. The vapors were eventually ignited by the water heater and flashed back along the carpet under the wall through the void to the puddle of gasoline in the garage. The ignition sequence from the water heater was due to the water heater's recycling to heat water after the wife had taken a shower.

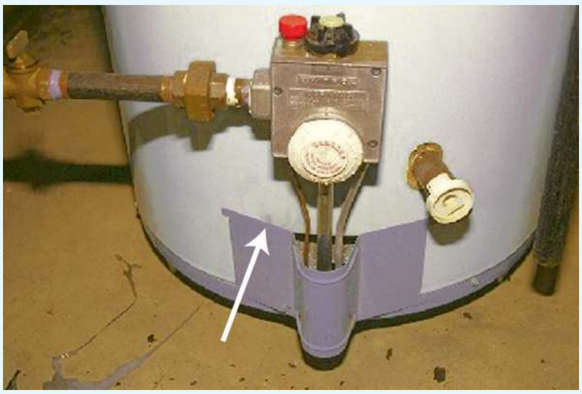


***Figure CS12.2.5*** Close-up view of the base of the water heater. The arrow indicates the soot mark caused by the ignition of the gasoline fumes by the burner of the water heater.

interior of the structure, it is important to evaluate the fire patterns in formulating an accurate conclusion about the point of origin of the fire. To properly identify the cause of the fire, it is necessary to examine all potential ignition sources at the point of origin. This would include the electrical utilities in the room, including electrical outlets, lighting equipment, and appliances. Heating equipment should be evaluated, including the normal domestic heat source for the room and any supplemental heating equipment such as space heaters or secondary heating equipment (e.g., fireplaces, wood stoves, gas-fired appliances, kerosene heaters). In addition to the normal potential heat sources, others that it may be necessary to identify and evaluate may include candles and smoking material, as well as certain chemicals that may be subject to spontaneous heating (stains, paints, or other natural oil products).

As one identifies and systematically eliminates potential heat sources to the point where all natural or accidental heat sources have been eliminated and the fire patterns indicate the potential use of an **accelerant**, the possibility of an **incendiary fire** cannot be eliminated. Further investigation includes securing samples from the point of origin to determine or identify a possible flammable or combustible liquid accelerant. It is necessary to take additional **control (comparison) samples** along with char samples. Comparison samples would include carpeting, wood flooring, linoleum, or certain furniture upholstery that may have been involved at the point of origin of the fire. The samples must be properly secured and identified as well as documented with photographs for future reference. As part of the origin and cause analysis, certain items may have to be secured and retained for other parties to examine as well. For example, if the fire is clearly accidental and an appliance has been identified as the cause of the fire, it is necessary to identify the manufacturer of the item so they may have an opportunity to examine the fire scene as well as the evidence. All parties involved in litigation may perform additional laboratory analysis or testing under a protocol agreed upon in advance.

## 12.4 Accelerants

An accelerant is the flammable material that is used to start the fire. Accelerants can be solids, liquids, or gases, with gasoline being the most commonly used. Solid accelerants include paper, fireworks, highway flares, and black powder. Butane (cigarette lighter fuel), propane, and natural gas are examples of gaseous accelerants, which do not leave any residue at a fire scene. However, gases must be contained and transported, so severed gas lines or spent containers serve as critical physical evidence in such cases. Liquid accelerants fall into two broad categories: petroleum distillates, which include gasoline and other petroleum products; and non-petroleum products such as methanol, acetone (used in nail polish remover), and turpentine. **Petroleum distillates** are derived from crude oil and are also called *hydrocarbons* or *petroleum hydrocarbons*. In crude oil, the volatility of the individual components ranges from extremely volatile substances such as propane (a gas at room temperature) to asphalt, which remains solid even at high temperatures. Petroleum distillates such as gasoline and kerosene are not single hydrocarbons but mixtures of different components with similar volatilities. The volatility of an accelerant is an important consideration in the combustion process, determining how much residue will be left and how quickly it will evaporate after the fire is out. Related to volatility is the flash point, defined as the temperature at which a liquid will give off enough vapor to form an ignitable mixture. At a fire scene, the presence of accelerants can be determined in several ways, including trained dogs, chemical color tests, and portable instruments and sensors. Materials such as wood and carpet absorb liquid accelerants, so samples of these materials can harbor valuable evidence.

## 12.5 Fatal Fire Investigation

The investigation of fires is a challenge because of the effects of the fire on the evidence (see Case Study 12.3). It is typical for a fire scene to be altered by the fire itself and, to some degree, the fire suppression efforts. To further complicate a scene, an incident with fatalities only highlights the importance of cooperation and thoroughness in the investigation. Not only is the investigator trying to investigate the origin and cause of a fire, but he or she is also potentially involved in a crime scene investigation and must determine both the cause of death and who or what was responsible for the victim's demise. To this extent, a thorough and time-consuming investigation must be pursued to separate those incidents that are tragic accidents from those that are criminal in nature.

Of utmost concern in a fatal fire is the potential loss of physical evidence. A fire will obviously alter evidence to some degree. How the evidence is identified, documented, and preserved is of paramount importance to the ultimate success of the case resolution. It is important and critical to document the scene thoroughly, including the relationship of the origin and cause of the fire to the victims. The victim's condition and position are important in later evaluation of the cause of death. Coordination of efforts at the fire/crime scene with the medical and postmortem investigation is equally important. Many times the local medical examiner or coroner will prefer to conduct his or her own on-scene examination of the victim's body before removal from the scene. Ultimately, the cause of death and cause of fire may be closely related if the victim was the perpetrator of the fire and succumbed to his or her own acts of negligence or intentional incendiary activities.

As for identifying fire victims, many times the fire is so intense that the only method of identification may be through medical or physical examination and autopsy. The most basic identification is known as gross identification whereby a relative or friend identifies the victim by visual identification. Additional identification may be by fingerprint comparison, forensic odontology (dental comparison), and ultimately medical or physical examination for tattoos or scars, evidence of surgical procedures, unique or unusual deformity, gender, race, build, features and approximate age, personal papers, jewelry, and clothing.

## 12.6 Collection of Fire Debris Evidence

During the course of a fire investigation, it may become necessary to collect and secure evidence for further testing or analysis to confirm or eliminate a potential fire cause. In most cases, the collection of evidence is critical in determining the cause of a fire loss. Evidence is usually defined as any finite or tangible material that is legally obtained in an effort to prove the cause of a fire. For the purpose of this discussion, we will focus on evidence securing, preservation, and testing as they relate to the public sector—that is, police agencies and fire municipalities. Many of these principles, however, also apply to the private sector, such as investigators for the insurance industry.

## CASE STUDY 12.3: INTENTIONALLY SET FIRE TO COVER UP A HOMICIDE

Although the incendiary fire investigation may initially commence on a similar path as the two previous examples, the fact remains that once this fire has been identified as a crime, the scene investigation takes on a dual role for local authorities. In this example, we encountered not only an intentionally set fire but also the motive to cover up a homicide. The unfortunate victim was a kind and generous grandmother who was dealt an untimely and unjustified death by her conspirators, a greedy daughter-in-law, grandson, and foster child.

The scene was a rural farm where the victim lived with her son and his family. To avoid any burden on them, she chose to live by herself in a mobile home on the property. Unfortunately, the son was a long-haul truck driver who was frequently absent, which left the burden of care to the daughter-in-law. Thus, the plot was hatched to dispose of the woman and inherit the entire estate with "no strings attached."

The plan commenced with the 14-year-old foster child distracting the victim in the living room area of the mobile home while the 27-year-old grandson prepared his "accidental" fire setup under the bedroom at the opposite end of the mobile home. In the early morning hours of the following day, they locked the door to the mobile home from the exterior by placing a screwdriver in the lock hasp of the door so the grandmother would be unable to exit the home once the fire began. The fire setup failed, so the grandson started the fire with a propane torch flame applied to the combustible underside of the bedroom floor. Smoke began to fill the mobile home and the grandmother was alerted to the impending danger of the fire, but her initial attempts to exit were prevented by the blocked door. Later, there was evidence that she attempted to break open the door with a hammer, which was found on the floor just inside the door as well as impact marks on the aluminum edge of the door frame. When this obviously wasn't going to work, she calmly removed the interior screen of the small window above the kitchen sink, climbed up onto the sink and out through the window to what she thought was safety.

This incident occurred one week before Christmas. There was heavy snow on the ground and extremely cold conditions. The grandson and foster child were on the lookout for any problems with their plan. When they heard her attempting to break the door down, they were waiting for her outside in the hedgerow. As she fell to the ground, they approached and struck her numerous times in the head with a steel pipe.

The daughter-in-law now thought that the fire had progressed sufficiently to call the fire department and allow the plan to unfold. When the fire department arrived with emergency medical services (EMS) close behind, they found the victim unconscious and bleeding in the snow outside the window. As the fire department proceeded to suppress the fire, which did not involve the opposite end of the mobile home, the EMS personnel treated the victim. They quickly stabilized the grandmother and began transporting her to the nearest hospital. En route to the hospital, they radioed to the emergency room and gave their initial assessment of the victim's injuries. The assessment included numerous and apparent skull fractures. This radio transmission was also relayed to the local authorities who responded to the fire scene to assist in the investigation. From the onset, the daughter-in-law, grandson, and foster child appeared remarkably calm throughout the ordeal.

As the investigation unfolded, it was apparent that the victim's ultimately fatal injuries were not consistent with the physical evidence at the fire scene. The three remaining witnesses were separated and interviews commenced while the on-scene investigation continued. The initial physical evidence regarding the fire quickly focused on the lack of an accidental ignition source under the bedroom area of the mobile home, such as an electrical ignition source or something related to the heating system. In addition, the unconventional method of exiting the mobile home through the window was puzzling because access to the mobile home was through the front door, which could not be locked from the inside or outside at first appearance. Upon closer inspection, the presence of the hammer on the floor just inside the door along with the unusual impact marks on the door frame raised suspicion. Closer inspection of the exterior hasp revealed unique indentations in the aluminum siding above and below the hasp. Further inspection of the area of fire origin in the bedroom of the mobile home confirmed suspicions about the fire cause. There was no accidental or natural ignition source in the bedroom since the fire vented through the floor under the bedroom from beneath the mobile home.

During interviews with the only witnesses, the first break came during the interview of the 14-year-old foster child. During his recitation of the events leading up to the discovery of the fire, he commented about getting a pony as his reward. Further inquiry into the "reward" revealed the entire story and conspiracy with the other members of the family. The plan was to make the death of the grandmother appear to be accidental while her son was away on a long-distance road trip. They carefully planned her demise. Initially, when the fire set did not go off as planned, the grandson set the fire with the propane torch by igniting combustibles under the bedroom area of the mobile home. He apparently assumed that the fire would destroy any evidence if the mobile home was extensively damaged by fire. The foster child was in charge of making sure that she could not escape from the mobile home by placing a screwdriver through the hasp to secure the door. Eventually, they saw her exit through the kitchen window, falling into the snowdrift below. At this point, they began beating her with the steel pipe. Once the fire was sufficiently in progress, the daughter-in-law called the fire department while the two young men hid the screwdriver and steel pipe in the barn. What was more disturbing about the case was that the 27-year-old grandson worked for the insurance company that carried the grandmother's life insurance policy. He apparently had devised the plan with his mother after reviewing the policy language.

Because the other parties to the conspiracy refused to cooperate and their stories were inconsistent with the information developed from the juvenile, it was necessary to obtain a search warrant. In the search warrant, the specific language was developed from the interview with the juvenile and identified specifically where the screwdriver and steel pipe were hidden. The screwdriver was recovered from an eaves trough on the edge of the main house roof. The steel pipe was recovered from two mattresses hidden in the hayloft of the barn. The screwdriver was compared to the marks on the outside of the mobile home door in the lock hasp and was determined to be a match. After photographing and documenting the measurements along with careful securing of the evidence for further laboratory testing and analysis, the three conspirators were arrested and charged with arson and homicide.

In the end, the juvenile was a state's witness against the two adults and served 2 years in a juvenile detention facility. The 27-year-old grandson was tried separately from his mother and sentenced to 25 years to life. As for the daughter-in-law, she was incarcerated in a local county jail pending her trial, but she passed away from a terminal illness approximately 1 month before her trial was to commence.

The investigation of fire losses has become more organized and thorough over the past 25 years. Many municipalities, even small volunteer fire departments, have their own fire investigation team. These teams of investigators are usually the first to investigate a fire scene after a fire is extinguished. Depending on the size of the loss, an arson task force may also be brought in to investigate the loss. Usually, if a fatality is involved, the task force or Fire Prevention Bureau will be summoned as a matter of standard operating procedures. In some instances when the dollar loss amount is exceedingly high, or if significant loss of life occurs, the local or state authorities may approach the Federal Bureau of Alcohol, Tobacco, Firearms, and Explosives (www.atf.gov).

Because the field of fire investigation has grown, the scrutiny of evidence collection, preservation, and testing has also increased. Criminal and civil cases depend on how evidence is collected and removed from the initial inspection date to the day on which it is presented in a court of law (Figure 12.2).

When the investigator believes that the cause of the fire could potentially be incendiary, samples of the burn materials around the point of origin should be removed and tested to identify the potential traces of accelerants. Some municipalities have accelerant detection dogs that are specifically trained to detect trace odors of accelerants. Many of the municipalities that handle or use accelerant detection dogs will remove samples of the flooring or other materials where the dog detects the odor of a potential accelerant.

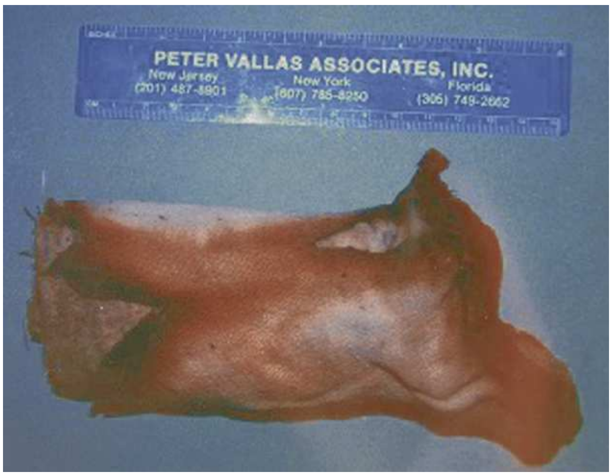



***Figure 12.2*** Closer view of rolled-up diaper that had been ignited and thrown on the bed. It was found to contain paint thinner.

When removing samples for testing, it is imperative that a comparison or control sample also be submitted. A control or comparison sample is the same material removed from a different room or different area of the room than where the fire originated. If a sample of carpeting is removed from the center of a specific room for testing, then a comparison sample of the same carpeting should be removed from a different room or possibly from a protected area, such as under a cabinet or furniture item, if possible. Laboratory tests will show if a potential flammable component is inherent in both samples. Whenever possible, only one type of material should be tested per sample. If a fire is determined to originate in the center of a room and the floor is a hardwood floor with carpeting, the investigator should have at least three samples to test to determine the presence of accelerants, as well as three control samples. The samples would include the carpet remnants in one sample, the carpet padding in a second sample, and the wood flooring in a third sample. If it is not possible and if the investigator removes only the carpeting and padding and places it in one sample container, then the control sample should also contain the carpeting and padding. Likewise, if a sample of flooring material consisted of vinyl tile and wood, a control sample of the same vinyl tile and wood flooring should be submitted for comparison purposes. For accelerant detection, unlined paint cans are the most common container used to collect fire debris evidence.

## 12.7 Analysis of Fire Debris Evidence

Many of the methods routinely used for the laboratory analysis of fire debris evidence are specified by the American Society for Testing and Materials (ASTM), which we mentioned briefly in the previous chapter with regard to methods of seized drug analysis. The primary tool used to detect and identify liquid accelerants is gas chromatography (GC) coupled to either a flame ionization detector (FID) or a mass spectrometer (MS). We have already discussed MS, and because these are rapidly replacing FIDs for fire debris testing, we will not discuss FIDs in detail. Analysis using either instrument produces an output that is distinctive for most common petroleum distillates. Patterns are identified by comparison to standards of known composition, a process called **pattern matching**, a practice we will see again in later chapters. The patterns obtained from evidence can be influenced by weathering and by microbial activity, particularly if the sample is on soil or vegetation. Weathering occurs as lighter (less volatile) components of the accelerant evaporate, and the longer the sample sits before collection the more severe the weathering effects. Samples are prepared for introduction into the GC using several methods:

1. *Cold headspace*—The can is punctured and a syringe is used to withdraw a headspace sample that is injected into the GC.
2. *Heated headspace*—Prior to syringe introduction, the can is heated.
3. *Extraction*—The accelerant is extracted from the sample using a solvent or steam. Small portions of the extract are injected into the GC.
4. *Purge-and-trap*—Inlet and outlet holes are put in the can lid. A stream of filtered air is pumped in through the inlet and a charcoal trap is placed on the outlet. The can may be heated, and vapors are trapped on the charcoal. The trapped compounds can be removed using heat (thermal desorption) or solvent extraction.

5. *Charcoal strip/solid-phase microextraction (SPME)*—A charcoal strip or other adsorptive material is lowered into the can or placed on an inlet drilled into the can. A vacuum can be used to draw a sample through the trap, or a stream of filtered air can be pumped into the can to force headspace to flow out through the trap. The can may be heated, with a thermometer inserted in the can to monitor temperature.

In some cases, the presence of a flammable material in a given area is to be expected and may not be associated with arson. If a fire is started in a garage where a car is parked and gasoline-powered equipment such as a snow blower or lawn mower is kept, the gasoline associated with the tools or car is considered to be an incidental accelerant that would normally be present in the area.

## 12.8 Explosives

Explosives are chemical compounds or mixtures that decompose rapidly to produce heat and gas. What distinguishes an explosion from combustion is the speed at which the reaction occurs. Explosions create huge amounts of gas that can travel at speeds of nearly 7000 miles per hour, and this shock wave or "blast effect" can do enormous damage to anything in its path. A detonation is actually not burning in the sense that you are used to thinking of it. Rather than being started by a match or flame, a detonation is initiated by pressure. A byproduct of the blast effect is an extremely loud noise created by the pressure wave.

Explosives can be categorized in many ways; one such division is into **low explosives** and **high explosives**. Low explosives burn very quickly and must be kept in a confined space to actually explode. Accordingly, low explosives are occasionally referred to as *burning explosives*. Examples of low explosives include smokeless powder (gunpowder), which is frequently used to make homemade explosives and pipe bombs. Another low explosive, made infamous by the Oklahoma City bombing on April 19, 1995 (Figure 12.3), is composed of ammonium nitrate and 6% fuel oil (ANFO). A similar mixture of urea nitrate and other materials was used in the first attack on the World Trade Center in 1993. The maximum burning speed of low explosives is around 1000 meters/second. Low explosives are sensitive to heat, friction, and sparks and are thus not very stable. The detonation of a low explosive generates what is referred to as *pushing power*, in which large objects are moved rather than shattered. Fragments of the container in which the explosive was placed are relatively large, and there are often significant amounts of residues remaining after the explosion.

High explosives can be further divided into primary and secondary explosives. Primary high explosives are shock and/or heat sensitive and are often used as primers that ignite secondary high explosives. Primers in ammunition and blasting caps contain primary high explosives. Secondary high explosives are much more stable and are usually detonated by the shock generated from a primary explosive. High explosives decompose at a much faster rate than low explosives, and detonations generate shattering power, produce smaller and sharper fragments, and generally leave minimal residue.

One of the oldest and most famous explosives is nitroglycerin, which was invented in 1847. Nitroglycerin alone is unstable and dangerous to handle, and it took refinements introduced by Alfred Nobel (of Nobel Prize fame) to package it in a stable form. By combining nitroglycerin with diatomaceous earth (DE), Nobel created

***Figure 12.3*** Scene of Oklahoma City bombing on April 19, 1995.

what came to be known as dynamite. Nobel, who was from Sweden, was a prolific inventor and is perhaps better known for the Nobel Prize, which his fortune created. The design of dynamite continued to evolve, the primary goals being to reduce its sensitivity to shock and to extend its usefulness in damp and wet environments. The military also has a number of high explosives, including trinitrotoluene (TNT), HMX, RDX, tetryl, and pentaerythritol tetranitrate (PETN). The terms “plastic explosive” or “plastique” usually refer to RDX mixtures that are moldable; “C4” is a complex that is 90% RDX.

Laboratory analysis of explosives and explosive residues utilizes a variety of techniques. When working with debris, preliminary microscopic examination can be helpful in identifying residues, but these are not always obvious among burned and blackened debris. Ones we have discussed and that are used include color and microcrystal screening tests, immunoassays, infrared spectrophotometry, GC-MS, and, increasingly, liquid chromatography (LC-MS). A number of screening and field-deployable devices have been used to identify explosive materials and devices. Such technologies are deployed at airports and at the scenes of mass disasters where explosives may have been involved. Common screening techniques include ion mobility spectrometry and x-ray scanning methods. Dogs can also be trained to sniff out explosives and are a common sight at airports and events that draw large crowds.

## Chapter Summary

Although the analysis of biological materials, seized drugs, and fire debris may not seem to have much in common, they are linked by the instruments and methodology of forensic chemistry. The concept of starting with a screening test and moving toward a confirmatory technique are common to all these areas, as are techniques and instruments such as color tests and GC-MS.

## 12.9 Review Material: Key Concepts and Questions

### 12.9.1 Key Terms and Concepts

Accelerant
Area of origin
Backdraft
Combustible liquids
Conduction
Control (comparison) samples
Convection
Explosion
Fire
Fire patterns
Fire point
Flammable liquids
Flashpoint
Glowing combustion
High explosives
High-order explosion
Ignition source
Incendiary fire
Low explosives
Low-order explosion
Pattern matching
Petroleum distillates
Radiated heat
Radiation
Spoliation

### 12.9.2 Review Questions

1. What is fire?
2. What is meant by the term incendiary fire?
3. What is the area of origin?
4. What is the point of origin?
5. In this context, what is meant by the cause of the fire?
6. What techniques can be used to identify the victim of a fatal fire?
7. List some common accelerants. Which is most common and why?
8. What is detonation and how is it different than a flame?

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# Section V Summary

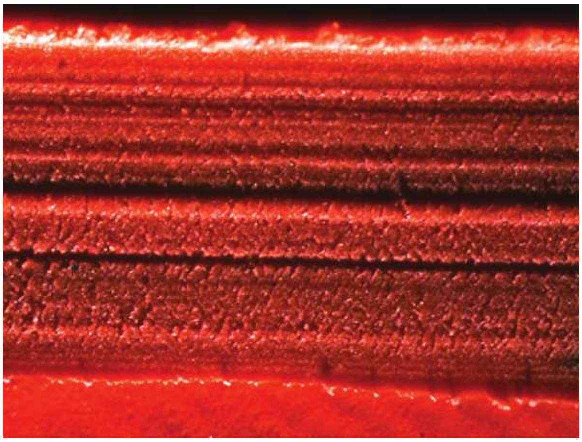
Forensic chemistry is a wide-ranging forensic discipline that spans many types of physical and biological evidence. The common theme that unifies all is the concept of applied analytical chemistry—the area of chemistry that focuses on the identification of chemicals in materials and in some cases the quantitation of these materials. The latter is particularly important in forensic toxicology, where the type and amount of drugs, poisons, or metabolites is critically important in determination of cause of death, for example. In later sections, we will see how analytical chemistry can contribute to questioned document analysis and trace evidence analysis.

## Integrative Questions

1. What are the fundamental differences between forensic toxicology and seized drug analysis? What are the similarities?
2. List analytical instruments that could be used in forensic toxicology, seized drug analysis, and explosives analysis. Be specific as to how each would be used in each discipline.
3. A body is discovered at the scene of a fire. What methods or procedures could be used to determine if the person was alive when the fire started or already dead? (*Hint:* Refer to earlier sections.)
4. Research a case involving improvised explosives such as the Oklahoma City bombing (1995) or the London subway bombing (2005). What types of explosives were used?

# SECTION VI

# Pattern and Impression Evidence



## Section Overview

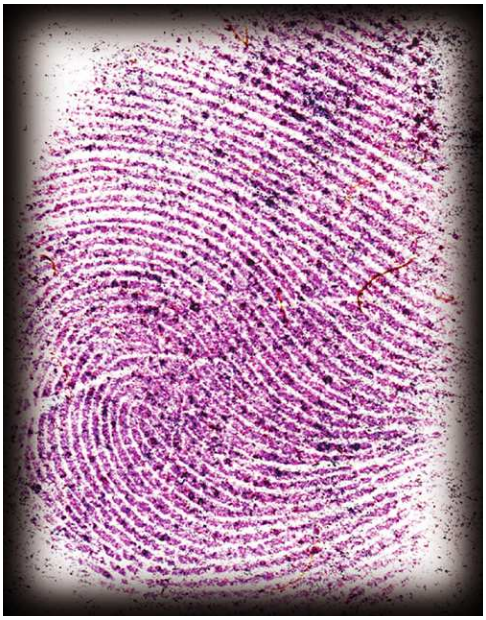
Physical evidence can be divided broadly into four major categories: drugs (Chapters 10 and 11), trace (Chapter 16), biological (Chapters 9, 10, and 11), and pattern evidence. The major members of the pattern and impression group are fingerprints (Chapter 13), tool mark and firearms evidence (Chapter 14), and other patterns such as footwear and tire impressions (Chapter 15). All of this kind of evidence consists of various patterns that can be compared to standards to determine if the source could have been the same or not. There is another kind of pattern evidence that could be called "reconstruction" patterns. This consists mainly of patterns usually found at scenes, such as blood spatter (Chapter 4), which are often used to help reconstruct events. Reconstruction patterns could also include the investigation of structure failures, suspicious fires, and transportation accidents (Chapters 12 and 18). In this section, we focus on classical forensic pattern evidence: fingerprints, firearms and tool marks, and tread impressions. In the next section, you will see that questioned documents (Chapter 17) are an area of forensic science that also has aspects of pattern matching.

One thing common to pattern evidence comparison is the generic methods used to make comparisons. Generally, an examiner will begin by looking for *class characteristics*. Let's say you are evaluating two shoeprints. Class characteristics could be used to identify one as coming from a boot and the other one as coming from a flip-flop. These are useful for differentiating the two prints and placing them into separate categories or classes. Now suppose you are comparing two shoeprints that are known to have been made by the same brand, model, and size of boot. How could you determine if the two prints came from the same boot or different boots? This is accomplished using an evaluation of *wear characteristics* (also called *individual* or *accidental characteristics* depending on the context).

Suppose one boot has been used daily for years as a work boot. The sole will be worn, scuffed, and marked in ways that a brand new boot would not. These characteristics are invaluable for comparing the two boot impressions. As we will see, this general method applies to all types of pattern evidence discussed in this section.

# 13

# Fingerprints



## Chapter Overview

Fingerprints as an evidence category is one of the oldest and most important in all forensic science. The use of these curious, highly individual friction ridge skin patterns on the end joint of the fingers as a means of personal identification dates back many centuries. Further, we have reached a point where fingerprint individuality is an article of faith among the public and is almost universally accepted among scientists and forensic scientists, as well. Accordingly, a fingerprint match is widely accepted as certain evidence that identifies a particular person. Still, fingerprint evidence is coming under increasing scrutiny, particularly the methods used to match a print to a person. As we will see, it is more complicated than you might expect.

# Chapter 13
# Fingerprints*

*Robert E. Gaensslen*

## Chapter Outline



## 13.1 Fingerprints as a Means of Identification

Because fingerprints are unique, they are used to identify people. In forensic science, we think of fingerprints as being used primarily to help locate, identify, and eliminate suspects in criminal cases. But fingerprints, along with DNA (Chapter 9), and dental remains, are also important in making unequivocal identifications of human remains when more conventional methods of postmortem identification cannot be used. Fingerprints may be thought of as one member of a class of biometric identifiers that would also include retina or iris patterns, face thermography, and some others. As the technology for rapid scanning and storage of these biometric patterns develops, they are becoming more important as security features to help avoid problems associated with forged identification documents. The two features of

* This chapter is based on Chapter 18, "Fingerprints," by R.E. Gaensslen, as published in the third edition of this text.

**SIDEBAR 13.1. CAREER PREPARATION AND EXPECTATIONS**

Until relatively recently, many fingerprint examiners began their careers as law enforcement officers and then moved into a forensic setting; however, current entry-level positions in latent fingerprint examination typically require a college degree in a natural science. The discipline requires many hours of training and apprenticeship under skilled and experienced examiners. Once trained, fingerprint examiners spend most of their time working in a forensic laboratory or office setting. Two useful online resources for finding more information are the International Association for Identification (http://www.theiai.org/disciplines/latent_prints/index.php) and the Scientific Working Group on Friction Ridge Analysis, Study and Technology (**SWGFAST**, http://www.swgfast.org/index.html).

fingerprints most important for their use as a means of personal identification are that (1) every fingerprint is unique (to an individual), and (2) fingerprints do not change during a lifetime (unless there is damage to the dermal skin layer). (For a discussion of career preparation for this field, see Sidebar 13.1.)

## 13.2 What Fingerprints Are

It has long been recognized that the fingers, palms of the hands, and soles of the feet of humans (and some other primates) bear **friction ridge skin**. These areas are characterized by a complicated pattern of hills and valleys. The hills are called **ridges**, and the valleys are called **furrows**. On the end joint of the fingers a number of basic patterns are formed by the friction ridge skin. Within each basic pattern are numerous possible variations. The patterns form on these skin surfaces early in embryonic development and remain constant throughout embryonic life, birth, and the life of the individual. An individual's genetic make-up probably plays a part in determining the sizes and basic shapes of the patterns and ridges, but it is not the only factor. We know this because identical twins, who come from the same fertilized egg and thus have identical genetic make-up, have different and distinguishable fingerprints.

## 13.3 Fingerprint Patterns

There are three basic fingerprint patterns: **arch**, **loop**, and **whorl** (Figure 13.1). Within these major classes, fingerprint examiners commonly recognize other categories. Arches, for example, can be plain or *tented*. Loops can be *radial* or *ulnar*, depending on whether the slope of the print pattern is in the direction of the inner arm bone (radius) or outer arm bone (ulna). Whorls are the most complex of fingerprint patterns, and there are several whorl categories, such as **central pocket**, **double loop**, and **accidental**. Loop and whorl patterns contain definable features called the **core** and the **delta**. These are important in ten-print fingerprint classification and in comparisons. Figure 13.2 shows some of the additional fingerprint patterns. The core and delta of a fingerprint pattern are also indicated in one of the frames.


***Figure 13.1*** Basic fingerprint patterns.

Within fingerprint patterns, there are a number of features called **minutiae**. Once evidentiary and reference (inked) fingerprints have been oriented and found to have the same general ridge flow or pattern type, these features are used to actually compare the fingerprints and decide whether or not they are from the same source. The ridges of the fingerprint form the minutiae by doing one of three things: ending abruptly (ending ridge), splitting into two ridges (**bifurcation**), or being short in length like the punctuation mark at the end of a sentence (**dot**). Combinations of these minutiae also have names; for example, two bifurcations

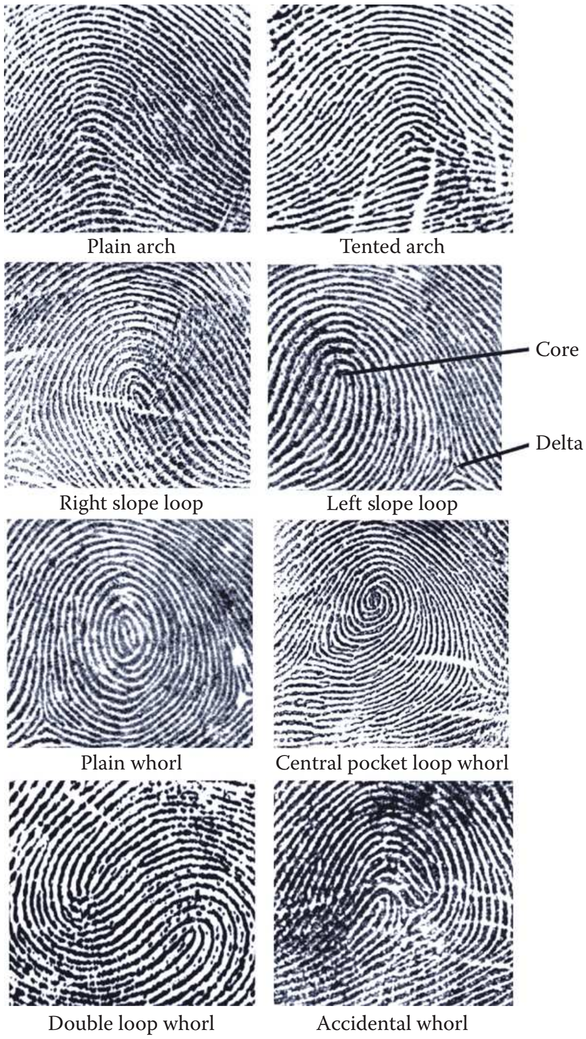



***Figure 13.2*** Variations of fingerprint patterns. One print shows the core and the delta.

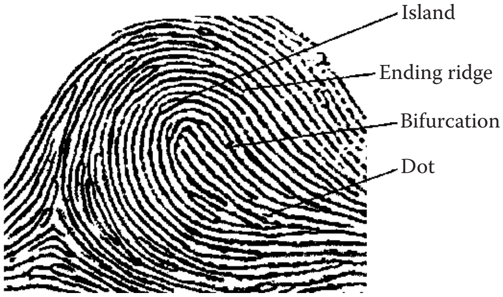



***Figure 13.3*** Fingerprint minutiae.

facing each other form what is called an **island**. Some minutiae are shown in Figure 13.3. The process used in fingerprint identification is discussed in more detail below.

## 13.4 History of Fingerprints

The use of fingerprint and handprint patterns as a means of personal identification dates back thousands of years. There are indications of this in artifacts recovered from archaeological excavations of ancient civilizations. Early potters may have used them to sign their work. There are records of using fingerprints and handprints as marks of authenticity in China at least 2000 years ago. We introduced key figures in the history of criminal identification in Chapter 1, including Bertillon and Galton. Indeed, development of fingerprint science in Europe dates back to the 17th and 18th centuries.

Sir William Herschel (Figure 13.4) is often credited with being the first European to recognize the value of fingerprints as a means of personal identification. Herschel was a British administrator who went out to work in Bengal, India, in 1853. He later joined the Civil Service of India. In his civil service capacity, he entered into a contract with a local businessman and asked that the man put his right hand print on the back of the contract. Herschel would later say that this action represented the first use of friction ridge impressions as a means of personal identification. It was apparently quite common, however, for parties to sign contracts in that area of India

***Figure 13.4*** Sir William J. Herschel (1833–1917). (From Berry, J. and Stoney, D.A., in *Advances in Fingerprint Technology*, 2nd ed., Lee, H.C. and Gaensslen, R.E., Eds., CRC Press, Boca Raton, FL, 2001. With permission.)

***Figure 13.5*** Dr. Henry Faulds (1843–1930). (From Berry, J. and Stoney, D.A., in *Advances in Fingerprint Technology*, 2nd ed., Lee, H.C. and Gaensslen, R.E., Eds., CRC Press, Boca Raton, FL, 2001. With permission.)

at that time by placing a hand or finger mark impression next to their signatures. And, as noted earlier, there is ample evidence that fingerprints were recognized hundreds of years earlier in China as means of identification. Herschel developed the use of fingerprints as a means of controlling fraud in contracts, false impersonations in government pension distributions, and other matters. He tried to convince others in the government to implement his practices but was unsuccessful. He nevertheless demonstrated the persistence of the ridge patterns in his own fingerprints taken periodically over a period exceeding 50 years.

Dr. Henry Faulds (Figure 13.5), a Scottish physician by training and profession, went to India as a medical missionary in 1871. The next year, he traveled to Japan. By 1879, he is known to have been involved in the study of fingerprints. In 1880, Faulds wrote a letter to evolutionary theorist Charles Darwin, who forwarded the letter to Francis Galton. Around 1880, Faulds noted that fingerprints could be classified and that ridge detail is unique. He further mentioned apprehending criminals by locating fingerprints at scenes. He appears to have been familiar with the Chinese and Japanese (perhaps even Egyptian) use of fingerprints. Many of his observations were recorded in a letter to the British journal *Nature* in 1880. There was some dispute between Faulds and Herschel over the priority of fingerprint use as a means of personal identification. In point of fact, neither of them could make such a claim. The originators of fingerprint science are lost in antiquity. It is fair to say that Herschel and Faulds were very influential in introducing the idea of fingerprints to continental Europe of the later 19th century.

Juan Vucetich might be considered the Western Hemisphere's fingerprint pioneer. An employee of the police department in La Plata, Argentina, he became convinced of the value of fingerprints as a means of criminal identification and wrote a book on the subject in 1894. By 1896, the Argentine police had abandoned Bertillonage in favor of fingerprints in criminal records. The first recorded case in which fingerprints were used to solve a crime took place in Argentina in 1892. The illegitimate children of a woman named Rojas were murdered on June 13, 1892. She acted distraught and accused a man called Velasquez, who she said committed the act because he wanted to marry her and she had refused. Velasquez maintained his innocence and had an alibi. An investigator from La Plata, the provincial capital, assisting with the case found out that another of Rojas' boyfriends had made statements about being willing to marry Rojas except for the children. The investigator, a man named Alvarez, having been trained by Vucetich, found a bloody fingerprint at the scene and collected it. After comparing it to Rojas' fingerprints, the bloody print turned out to be of her right thumb. She confessed when confronted. Vucetich devised a classification system for fingerprints that was used in Argentina and throughout South America.

In North America, fingerprints were being used by the New York City civil service (to prevent impersonations during examination) by 1903, and the use of fingerprints was introduced at about the same time in the New York State prison system and at Leavenworth Penitentiary. A number of police departments began using fingerprints as identifiers in criminal records, as well. The 1904 St. Louis World's Fair provided the venue for a chance meeting between Inspector Edward Foster of the Royal Canadian Mounted Police (RCMP) and Detective John Ferrier of Scotland Yard. As a result of what he learned in St. Louis, Foster convinced his superiors in the RCMP of the utility of fingerprints. In 1910, a man called Thomas Jennings was arrested in Chicago and brought to trial for murder. The primary evidence against him was fingerprints. The state wanted to try to ensure that the fingerprint identification evidence would survive appeals to the Illinois Supreme Court, so they called Edward Foster as an expert witness. The defendant was convicted, the evidence did survive, and the Jennings case is considered a landmark fingerprint case in the courts.

## 13.5 Fingerprint Classification

It was apparent to the early fingerprint pioneers that a manageable, consistent classification system was necessary if large sets of fingerprint files were to be useful for criminal identification. In the United Kingdom and the United States, the classification systems are variants of the one developed by Sir Edward Henry. In Argentina and other South American countries, a different system based on the one developed by Vucetich has been used. The modified **Henry system** as used in the United States is a scheme for the classification of ten-print sets, or a fingerprint card, for one individual. Figure 13.6 shows a typical fingerprint card of the kind long used by law enforcement and other agencies to maintain fingerprint records. Use of the classification system enabled efficient searching of large files. Keep in mind, though, that classification is based on having all ten prints. Thus, a ten-print card from a fingerprinted person can be classified and filed, but you would need all ten prints from a person to use that person's classification to search in the large file. The system allowed organized maintenance of the large files maintained by many law enforcement agencies, but the files could not easily be searched manually for a single print. It is typical to recover single prints, or sometimes even partial single prints, from crime scenes. Until the development of computerized fingerprint search systems, it was impractical to search large files for a single print because it took so much time. Partial prints could obviously be compared with prints from cards on file, but it was necessary to have a possible suspect or suspects first to know which cards to retrieve for manual comparison.

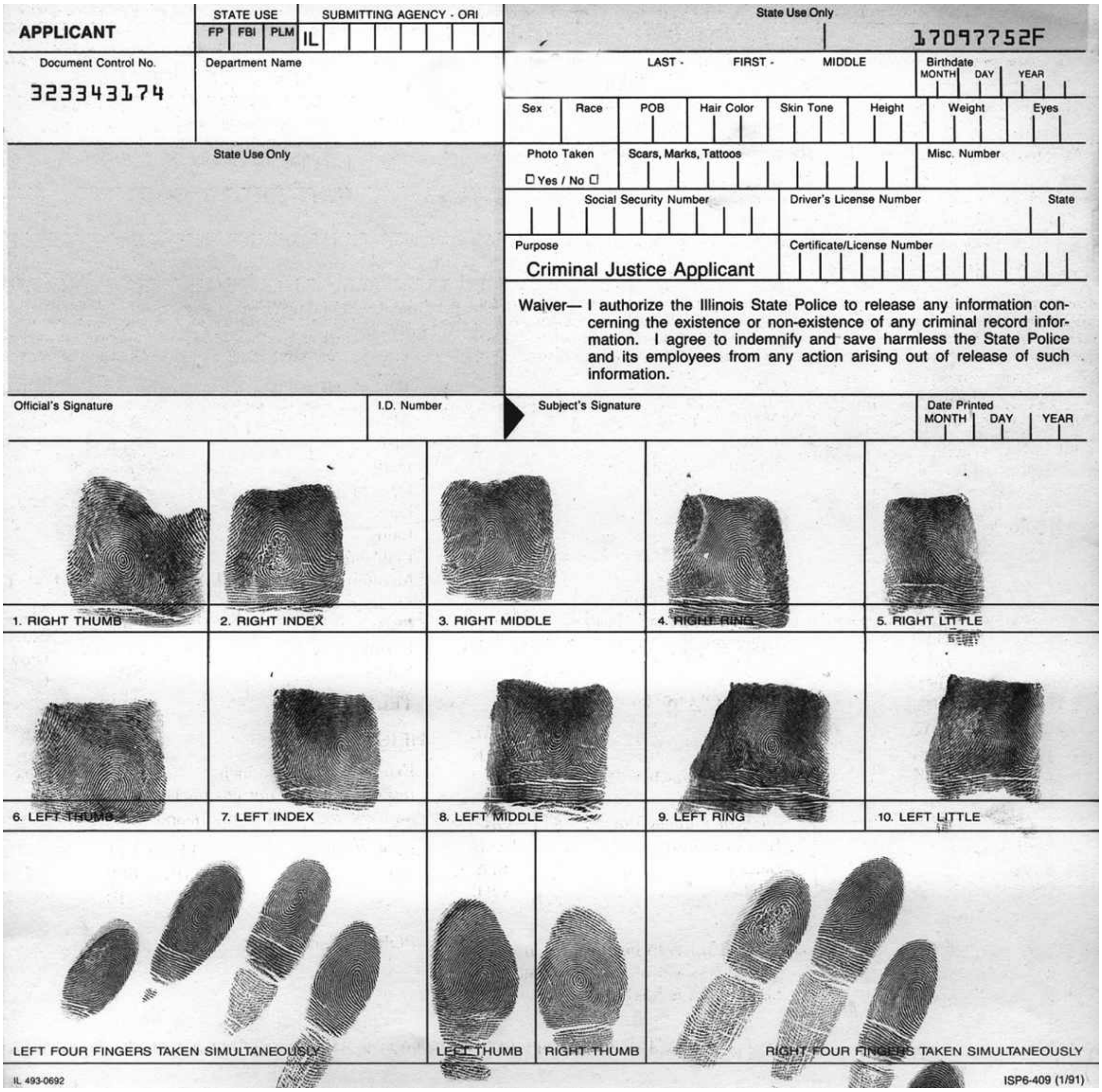



***Figure 13.6*** Typical ten-print fingerprint card.

The development and fairly widespread deployment of computerized fingerprint storage and retrieval systems have made searching large files for single and partial prints routine. These systems have also rendered classification largely unnecessary. At one time not long ago, all fingerprint examiners and identification personnel were extensively trained in fingerprint classification using the modified Henry system, as were many police officers. Figure 13.7 summarizes the modified Henry classification of a ten-print set as used by the Federal Bureau of Investigation (FBI).

## 13.6 Computer-Based Fingerprint Files

Computer storage and retrieval systems for fingerprints were originally developed for law enforcement applications. Efforts to develop these systems began in the early 1960s. In the United States, these efforts were the result of collaboration

| Key | Major | Primary | Secondary | Subsecondary | Final |
|---|---|---|---|---|---|
| 10 | M | 19 | U | IOM | 1 |
| | 14 | 21 | W | OII | |

**Key** = The ridge count of the first loop pattern excluding the little fingers.

**Major** = Value of the ridge counts of the loop patterns or the tracings of the whorl patterns on the thumbs (fingers #1 and #6).

**Primary** = Summation of the value of the whorl patterns for fingers numbered 2, 4, 6, 8, and 10 for the numerator (top). Summation of the value of the whorl patterns for fingers numbers 1, 3, 5, 7, and 9 for the denominator (bottom). Add 1 to both the numerator and denominator.

**Secondary** = Pattern types located in the index fingers (#2 and #7).

**Subsecondary** = Value of the ridge counts of the loops or the tracings of the whorls for fingers #2, #3, and #4 in the numerator (top) and #7, #8, and #9 in the denominator (bottom).

**Final** = The ridge count of the loop in the right little finger (#5), if it is not a loop then use the left little finger (#10). If there is no loop in either of the little fingers, then there is no final.

***Figure 13.7*** Summary of modified Henry system fingerprint classification.

between the FBI, which maintains the largest (and only national) fingerprint database, and scientists at the National Bureau of Standards (which later became the National Institute of Standards and Technology, or NIST). A law enforcement-based automated system is commonly referred to as an **Automated Fingerprint Identification System (AFIS)**. There are two principal applications. The first is searching large files for the presence of a ten-print set of prints (taken from a person). The second is searching large files for single prints, usually developed latent fingerprints (see below) from crime scenes. Developing the appropriate scanning and storage technologies and computer algorithms for these systems was far from trivial.

By the late 1980s, there were at least five operational AFISs, at least four of which had been commercialized. Most, if not all, large jurisdictions had systems in place by the 1990s. Because different commercial vendors use different technologies, the systems are not intrinsically compatible with one another. Another important point about AFISs is that a given person's fingerprints may be in one system but not in others. Depending on the criteria for including a set of prints in the files, a large city system could have someone's prints, but the corresponding state system might not have them, for example.

An AFIS database holds two types of files or profiles. One type is the knowns, which are prints of known individuals. Any questioned specimen, image, or profile can be searched for in the known database, and when found its source is thereby identified. The other type is often referred to as the forensic file or database, which consists of images or profiles from unsolved cases, the sources of which are not known. An AFIS forensic file contains images of developed latent single fingerprints from unsolved cases. The person whose fingerprints these are has not yet been identified. The file is valuable to investigators, however, in that it allows cases that were not obviously related to be connected by fingerprints. Such connections can allow investigators to share information and leads, thus increasing the probability of apprehending a suspect.

The AFIS has become a successful tool in the apprehension of unknown offenders. Traditionally, any person arrested would have a ten-print card entered into the AFIS system. Many job applicants will also have a ten-print card in the system. The number of cases solved by AFIS in the United States is difficult to determine, but the national average of latent prints entered into AFIS that will be deemed an identification by a latent print examiner is around 15%. This average of latent prints identified by AFIS can vary among jurisdictions. It is dependent on the knowledge and skill of the individual entering the latent or unknown impressions (usually forensic scientists) and also by the individuals that submit and register the known fingerprint cards (usually technicians or police personnel).

The FBI has made their criminal database of known fingerprint cards available to other law enforcement agencies through its **Integrated Automated Fingerprint Identification System (IAFIS)**, which allows a latent print examiner to search unknown latent impressions in a neighboring state or several states. IAFIS is a national criminal database maintained by the FBI of all of the 10-print cards received from all over the country. To date, this system has been very successful in developing leads and sometimes solving unresolved cases.

Today, AFIS must be seen as part of a much larger picture that includes an array of automated systems for human **biometrics**—the use of some type of body metric for identification. It may be fair to say that the Bertillon system of anthropometry described in Chapter 1 was the first well-defined system of human biometry, leaving aside the pre-19th century uses of fingerprints as means of human identification.

Although criminal identification and related law enforcement applications of automated fingerprint systems are obviously very important, fingerprints along with other biometrics (such as retinal or iris patterns, voice recognition, or hand geometry) have increasingly been incorporated into automated identification systems for other purposes. These systems may control entry and/or access into computers or structures, allow identification of persons for security purposes, prevent identity theft, and help control welfare or social services fraud.

## 13.7 Types of Evidentiary Fingerprints

At crime scenes or on items of evidence, there are essentially three types of fingerprints that may be encountered: **patent, plastic**, and **latent**. A patent (or visible) print is one that needs no enhancement or development to be clearly recognizable as a fingerprint. Such a print is often made from grease, dark oil, dirt, or even blood, rendering it visible and recognizable and possibly even suitable for comparison without additional processing. A plastic print (also referred to as an *impression* or *indented* print) is a recognizable fingerprint indentation in a soft receiving surface, such as butter, putty, tar, etc. Such prints have a distinct three-dimensional character, are immediately recognizable, and often require no further processing. A latent print is one that by definition requires additional processing to be rendered visible and suitable for comparison. Processing of latent prints to render them visible and suitable for comparison is called **development**, **enhancement**, or **visualization**. An enormous amount of literature on this subject has been published over the past 30 years or so. Many great strides have been made in the area due to clever applications of chemistry and physics principles coupled with better understanding of the composition of latent residues. In many ways, these advances are as impressive and important as the progress made in applying DNA typing techniques to biological evidence, though they have not received even a fraction of the publicity that has been given to DNA.

## 13.8 Development of Latent Fingerprints

### 13.8.1 Composition of Latent Fingerprint Residues

The starting point for understanding latent print development techniques is the fingerprint residue itself. Friction ridge skin (Figure 13.8), as found on the surfaces of the fingers, hands, and bottoms of feet, has pores through which small sweat glands can empty their contents onto the skin surface. These sweat glands, called **eccrine**, produce the watery-type sweat composition of which forms a basis for latent fingerprint residue. Another type of sweat gland called **apocrine**, located in other parts of the body, produces sweat that contains organic molecules (lipids and proteins) and pheromones. This material can become part of the latent print residue from a person touching those areas of the body. In addition, an almost unlimited variety of substances from the environment can get onto the friction ridge skin and then be deposited into latent residue when the person touches a surface. Thus, although there are a number of common constituents of most latent print residues based on the composition of sweat, the proportions may vary, and there are many other compounds and materials from the environment that can be present as well. Table 13.1 shows some of the common constituents.

Most methods for the development of latent prints were developed based on knowledge of the latent print residue composition. Usually, a method known to be capable of detecting or visualizing one of the compounds or elements present in latent residue has been applied to target that compound or element. For the application to be successful, it has to be possible to apply the method to evidentiary fingerprints on the variety of surfaces where they are found, and without destroying the integrity of the impression pattern. The methods commonly employed can be broadly divided into three groups: physical, chemical, and special illumination, or a combination of these methods, many of which involve laser or narrow band pass illumination.

It should be noted here (and will be reiterated below) that fingerprints developed *in situ* at a scene must be photographed prior to any lifting or other collection effort. Prints developed in the laboratory or identification unit must also be photographed to document the results as well as the location of the print on the evidence item. Investigators often face difficult decisions about whether to employ fingerprint enhancement procedures at a scene or to seize the evidentiary item and submit it to the lab or identification unit. Many factors will be involved in resolving

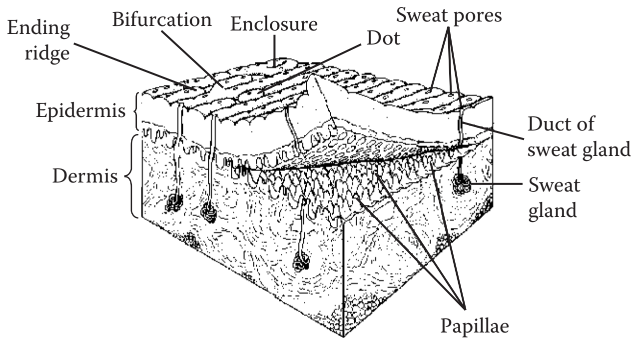



***Figure 13.8*** Friction ridge skin—diagram of longitudinal section. (From FBI, *The Science of Fingerprints*, Rev. 12-84, Federal Bureau of Investigation, Washington, DC, 1984.)

**TABLE 13.1**
**Constituents of Fingerprint Residue from Sweat**

| Major Components | Minor Components |
|---|---|
| *Inorganic* | |
| $Na^+$ | $Mg^{++}$ |
| $K^+$ | $Zn^{++}$ |
| $Ca^{++}$ | $Cu^{++}$ |
| $Fe^{++}$ | $Co^{++}$ |
| $Cl^-$ | $Pb^{++}$ |
| $F^-$ | $Mn^{++}$ |
| $Br^-$ | |
| $I^-$ | |
| $HCO_3^-$ | |
| $PO_4^{3-}$ | |
| $SO_4^{2-}$ | |
| $NH_4OH$ | |
| *Organic* | |
| Proteins | Pyruvate |
| Amino acids[a] | Creatine |
| Lipids[b] | Creatinine |
| Glucose | Glycogen |
| Lactate | Uric acid |
| Urea | Vitamins sterols |

[a] Major amino acids (serine, glycine, ornithine, alaine, asparticacid).
[b] Major lipids (fatty acids, triglycerides, wax esters, squalene).

the matter, including the training and experience of the investigator, how well equipped the investigator is at the scene, and whether the evidentiary item can be readily seized and transported.

### 13.8.2 *Physical Methods*

Classically, physical methods are those that do not involve any chemicals or chemical reactions. They work by applying fine particles to the fingerprint residue where it adheres preferentially, thus creating contrast between the ridges and the background. The most well-known one is **powder dusting**—a mainstay of latent fingerprint detection for a century or more. Most common powders are inorganic and come in several colors. There is also a large variety of fingerprint brushes available. The principle of powder dusting is simply that the powder particles adhere to the latent residue. Careful use of the proper brush and powder often results in the development of excellent prints. Black powders are generally superior to the other colors. Black powders are produced in a way that yields more uniform particle size and generally produces better results. The technique is illustrated in Figure 13.9. Also illustrated is the lifting of a developed latent impression using transparent lifting tape. The tape lift is mounted on a backing card with a color maximally

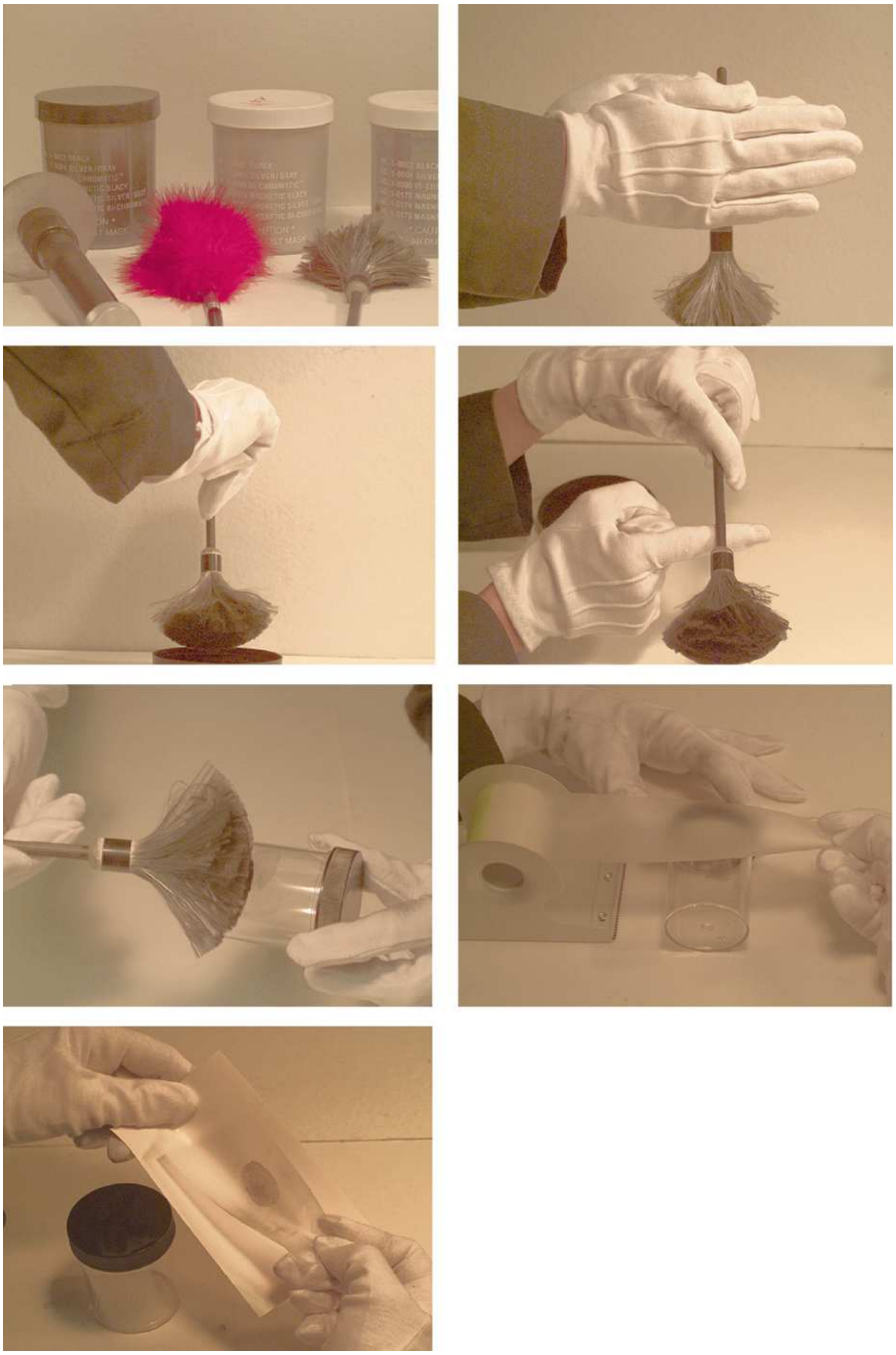


***Figure 13.9*** Technique of powder dusting a latent fingerprint and transparent tape lifting.

contrasting to that of the powder (e.g., white backing for black powder). One-piece lifters, also known as **hinge lifters**, are commercially available for this purpose. A latent fingerprint developed by powder dusting is shown in Figure 13.10. A variant of the simple brush and powder combination is the magnetic brush (Figure 13.11), the original trademark version of which is called the **Magna Brush**. Actually a small retractable magnet, not a real brush at all, the magnetic brush uses special magnetic powders that also can be obtained in several colors. The principle of magnetic powder enhancement is the same as for conventional powder—namely, adherence of the fine particles to fatty components of the residue. The magnetic


***Figure 13.10*** Latent print before and after powder dusting.

***Figure 13.11*** Magna Brush and magna powder (left) and developed latent print (right).

brush technique is more useful on some surfaces than conventional powder dusting, mainly because the magnetic wand can be used to remove any excess powder from the substratum. It also has the potential to be a gentler technique, in the sense that there is no brush and thus no bristles, so it is less likely to damage the latent print ridges in the brushing process.

Another physical latent print developing procedure involves **small particle reagents (SPRs)**. Typically applied by spraying or immersion, the most common formulation of SPRs is a fine suspension of molybdenum disulfide in a detergent solution. The particles adhere to the lipid components of the residue. SPRs are most commonly used on evidence that has been formerly wet.

### *13.8.3 Chemical Methods*

The greatest progress in latent fingerprint visualization techniques in the past quarter century has involved chemical and instrumental/special illumination techniques. Classically, the chemical techniques were **silver nitrate**, **iodine fuming**, and **ninhydrin**. Silver nitrate is not used any longer because much better techniques are available. The principle of its use lay in the reaction of the silver with the chloride in the fingerprint. The silver chloride was then photoreducible to silver, which contrasted with the background. A somewhat related method that still involves silver is called **physical developer (PD)**, which is discussed below.

Elemental iodine is one of the compounds in nature that sublimes; that is, it can pass from solid to vapor without becoming liquid. Iodine sublimes easily with only moderate warming. The vapor is directed toward the fingerprint residue with a so-called iodine fuming gun (essentially a plastic blowpipe containing some iodine), or an object to be fumed can be placed in a closed cabinet, which is then filled with iodine fumes. Even though it has long been placed under the "chemical methods" category of latent print development, the iodine probably does not react with any of the components in the residue. It probably interacts with the lipid components in such a way that it is trapped in the residue, giving the ridge features a dirty-brown colored appearance. The iodine-developed color is not stable in the latent print, however, and iodine prints have to be quickly photographed. There are chemical methods for rendering iodine prints a permanent color that will not fade. The traditional method involved using starch solution for that purpose, but 7,8-benzoflavone (α-naphthoflavone) treatment is the preferred method today. Iodine fuming is used primarily on inherently valuable items precisely because of its impermanence.

Since around 1910, ninhydrin has been known to react with amino acids, forming an adduct called **Ruhemann's purple** (named for one of the original observers). In the mid-1950s, Swedish scientists noted that ninhydrin reacted with the amino acid components of latent fingerprint residue, and they took out a patent on the process. Ninhydrin is applied by spraying, painting, or dipping. The ninhydrin reaction is slow unless accelerated by heat in the presence of humidity. The classical ninhydrin preparation was made up in Freon 113 (1,1,2-trichlorotrifluoroethane). Concern over the effect of these compounds on the Earth's ozone layer culminated in the signing of the Montreal Protocol in 1987 in which many countries agreed to ban the use of chlorofluorocarbons (CFCs), of which Freon 113 is an example. The most recent ninhydrin formulations have thus avoided the use of Freon as a solvent.

Ninhydrin develops bluish-purple fingerprints (Figure 13.12A) and is extremely useful on porous surfaces (such as paper), but occasionally the bluish-purple color may not show sufficient contrast with the background substratum. Ninhydrin is also useful as a preliminary treatment in a sequential process followed by other chemicals and viewing under laser or alternative light source illumination. Another significant factor in ninhydrin use for latent prints has been the design, synthesis, and evaluation of a series of ninhydrin analogs, perhaps the most important of which is 1,8-diazafluoren-9-one (**DFO**). Treatment of ninhydrin-developed prints with $ZnCl_2$ (zinc chloride) provides the basis for the use of laser and special illumination methods. The metal salt treatment converts Ruhemann's purple to another compound that can be excited by blue–green light using a laser or alternative light source to yield strong fluorescence. Many modifications of post-ninhydrin latent print treatments have been designed to maximize fluorescence under illumination by commercially available lasers or broadband pass filtered alternative light sources.

Many other chemicals react with amino acids to yield colored or fluorescent products; however, none has been as important in operational latent print work as ninhydrin (and post-treatments) and DFO. The most important other chemical procedure is treatment with **cyanoacrylate** esters (**Super Glue®**, or instant glues). Super Glue enhancement was first observed by Japanese scientists in the National Police Agency. The method quickly caught the attention of latent print examiners all over the world. In the early 1980s, fingerprint examiners working in the U.S. Army Criminal Investigation Laboratory in Japan and a little later in the Federal Bureau of Alcohol, Tobacco, Firearms, and Explosives Laboratory, introduced alkyl-2-cyanoacrylate ester (Super Glue) fuming as a method for latent print development in the United States.

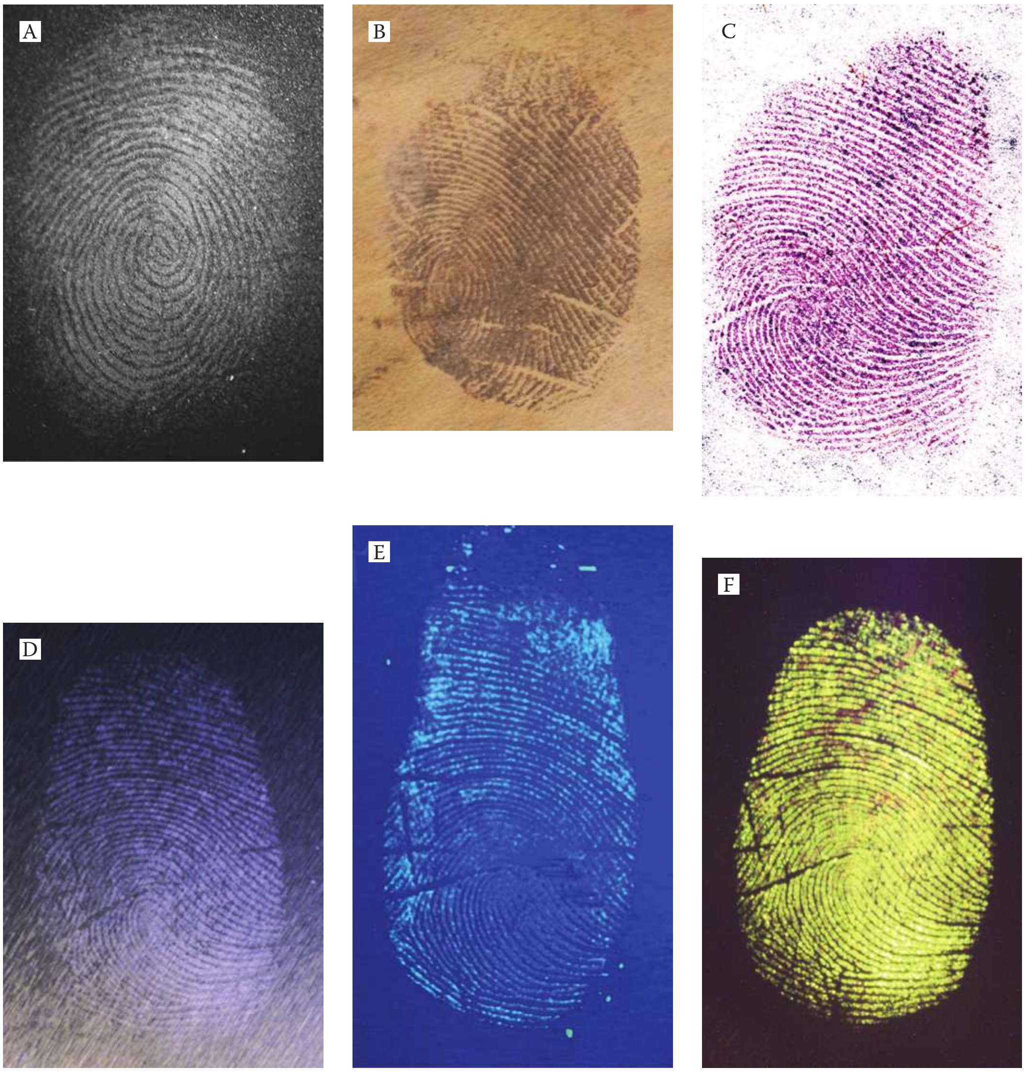



***Figure 13.12*** Visualization of latent fingerprints by various methods. (A) Ambient (oblique) white light illumination; (B) physical developer; (C) ninhydrin; (D) cyanoacrylate ester (Super Glue); (E) Super Glue-developed print, post-treated with ardrox dye, under UV illumination; and (F) Super Glue-developed print, post-treated with Rhodamine 6G, under UV illumination.

Super Glue can be induced to fume, and the fumes will interact with latent fingerprint residue by polymerizing *in situ*, yielding a friction ridge impression off-white in color. Items to be processed by glue fuming are usually placed into well-sealed cabinets where the glue is induced to fill the cabinet with vapors. The process requires a certain level of relative humidity, and a moisture source is always placed in fuming cabinets. Glue fuming can be accomplished in a closed cabinet or container without any acceleration, but it is very slow. Typically, strong alkali or heat is used to accelerate fuming. The progress of latent residue development in the fuming cabinet can be monitored by placing a test latent print onto a piece of aluminum foil, or similar surface, and placing the object into the cabinet where it can be viewed during fuming. Latents underdeveloped with Super Glue can simply be further fumed, but overfumed latents may be ruined.

Like ninhydrin, glue fuming is an excellent method of developing latent fingerprints, but it may be most useful operationally as an initial step in protocols where the cyanoacrylate-developed prints are further treated and examined. The simplest enhancement of a cyanoacrylate-developed print is dusting it with powder. Other post-treatments of cyanoacrylate-developed prints include dye stains, which induce luminescence or fluorescence in the residue when it is illuminated with laser or alternate light source at the appropriate wavelength. Gentian violet, Coumarin 540 laser dye, Ardrox, Rhodamine-6G, and other treatments have been used for the enhancement of cyanoacrylate-developed print luminescence under alternative light or laser illumination.

The last chemical method we will discuss is physical developer. In spite of the name, physical developer (PD) is a chemical method. It has become common in many laboratories to use PD as a follow-up method to ninhydrin or DFO on porous surfaces, such as paper. Whereas ninhydrin or DFO react with water-soluble components in the latent print residue, PD reacts with the lipid and other water-insoluble components. PD is a photographic-type process based on the deposition of silver onto latent fingerprint residue from a ferrous/ferric redox couple and silver salt mixture in solution. A modified procedure developed at the U.S. Secret Service laboratory employs colloidal gold in addition to silver salt.

### *13.8.4 Combination/Special Illumination*

Sometimes a latent fingerprint can be visualized by simple **oblique lighting**. This technique might be considered physical, as it involves no chemicals or special light sources. A latent print amenable to visualization by oblique lighting also illustrates that the definition of a "latent" fingerprint is operational to a large extent. Some kind of pattern must be visible in order to prompt the observer to obliquely illuminate the surface, thus enhancing it. Latent prints may also be viewed under alternative light (525 nm) or laser illumination. Alternative light is generally superior to incident white light in revealing ridge detail. Alternative light sources are exceptionally bright (such as xenon arc) white light sources. White light is a mixture of wavelengths between about 300 and 800 nm on the electromagnetic spectrum. Alternative light sources are supplied with colored filters, which serve to filter the source light so the developed latent print can be viewed with light of a narrow wavelength range. The filter is selected to induce illumination at the wavelength known to excite the chemical compounds used in the latent development procedure. Other filters may be used to view the luminescence resulting from the alternative light source excitation. The luminesced light will be of longer wavelength than the excitation, and the filter may provide sufficient contrast between the background and the luminescence of the latent print ridges to give a useful ridge detail image that can then be photographed and used for comparison. A laser is also a very high-intensity light source, but it emits light of a single wavelength (monochromatic light). Several lasers are commercially available. Methods have been developed over the years to take advantage of the excitation wavelengths afforded by these lasers. The most recent development in this context is development of luminescent nanoparticles for latent fingerprint enhancement.

### *13.8.5 Bloody Fingerprints and Other Special Situations*

Latent fingerprints in blood or on certain unusual types of surfaces require special techniques, enhancement modalities, or approaches. Bloody fingerprints are almost by definition not latent. Some type of pattern is visible in the blood, and investigators may recognize that the pattern is probably a fingerprint (or palm or foot print), but the ridge characteristics are not sufficiently well defined to make the print suitable for comparison. In these circumstances, the use of a bloody fingerprint enhancement reagent might be considered. In this context, an investigator needs to think about whether it will be necessary to attempt to do DNA profiling of the blood that is forming the apparent ridge patterns. There is substantial published evidence that latent fingerprint chemical enhancement procedures, including those designed for bloody prints, do *not* interfere with subsequent DNA profiling by polymerase chain reaction (PCR) for the now-universal (at least in the United States) Combined DNA Index System (CODIS) core short tandem repeat (STR) loci.

Bloody fingerprint enhancement reagents can be sprayed or squirted from a wash bottle. Some of the formulas result in a reagent that is not very stable in solution and, thus, has almost no shelf life. Therefore, they need to be prepared shortly before use. Further, there are serious chemical hazards associated with some of the ingredients, so some training is required in the proper preparation and use of these reagents. Many bloody fingerprint enhancement reagents are based on the peroxidase reaction chemicals, such as phenolphthalein, commonly used as presumptive tests for blood (Chapter 8).

Another special situation involves fingerprints deposited on tape, especially on the adhesive surface. Techniques involving staining with crystal violet were traditionally used for this kind of latent impression. Today, the most commonly used method for developing this kind of impression is use of a material called *sticky-side powder*, which is actually composed of lycopodium (a plant) pollen mixed with a detergent and water. The sticky-side powder slurry is painted onto the adhesive side of the tape with a brush, and the tape is then rinsed off with water. The process can be repeated until the desired contrast has been achieved, and it often yields identifiable prints. Sticky-side power can be used on almost any kind of tape and works especially well on duct and electrical tape.

Yet another special situation deserving brief mention is the development of latent prints on human skin. A variety of different techniques have been tried, but with only modest success and even then in select cases. A generally useful procedure has not emerged thus far.

### 13.8.6 Systematic Approaches

This concept is probably followed by most latent fingerprint examiners even if they do not identify it as such. The idea is to apply latent development techniques in a way that maximizes the number of identifiable prints. The least destructive technique is applied first, and techniques are generally applied in a sequence that allows the maximum number to be used if necessary. Systematic approaches vary according to the surface or substratum on which the latent is located. Porous surfaces, such as paper, for example, call for a different set of techniques applied in a different sequence than nonporous surfaces.

## 13.9 Recognition, Collection, and Preservation of Fingerprint Evidence

Fingerprints are among the best and most probative of all types of physical evidence for associating people with locations or objects. Accordingly, fingerprint evidence should be sought at any type of scene, and particularly at scenes of crimes committed by unknown perpetrators. As a general rule, objects believed to have latent fingerprints on their surfaces should be collected intact and submitted to the laboratory's latent print section for examination. If collection of the object or surface is impossible or impractical, investigators must consider applying latent development techniques at the scene or requesting assistance from personnel trained to do so. Sometimes, developed prints may be collected using tape-lift or other methods. Other times, the developed print may have to be carefully photographed because the photograph will be the only permanent record of the evidentiary print. Like other evidence, collected fingerprint evidence such as lifts or photographs should be carefully documented to preserve the chain of custody from the scene to the courtroom.

## 13.10 Fingerprint Identification: The Heart of the Matter

Everything in this chapter so far—indeed, the reason there is a chapter on this subject at all—comes down to the use of fingerprints as a means of identification of persons. As noted earlier, the uniqueness of fingerprints is a matter of common knowledge. Advertisements and commercials commonly use phrases such as "… as unique as a fingerprint." Even the term "DNA fingerprint," as undesirable and sometimes misleading as it is, was coined to reflect the notion that a DNA profile might be as individual as a fingerprint. Infrared spectra of pure compounds are sometimes called "chemical fingerprints." Most people, however, have never given much thought to the process by which fingerprint identification is actually done. Fingerprint identification rests on four premises:

1. Friction ridges develop during fetal growth before birth in their definitive form.
2. Friction ridges remain unchanged throughout life with the exception of permanent scars.
3. The friction ridge patterns and their details are unique and not repeated.
4. The ridge patterns vary within certain boundaries, which allow the patterns to be classified.

Fingerprint examiners are generally extensively trained and required to accumulate significant experience before being entrusted with the responsibility of making identifications. Thus, in addition to the general principles and approaches used to make identifications, the knowledge, training, and experience of the examiner also come into play. Even so, sometimes things can go wrong, as described in Case Study 13.1.

In a law enforcement context, identifications are always made by trained, and often certified, examiners. Sometimes, inked prints from a person may be compared with a set of inked prints on file to determine if they came from the same individual, but more commonly the examiner will be comparing a developed latent print with inked prints from a known person or persons. AFIS searches can quickly narrow down the number of possible matches to a manageable size, but an examiner, not a computer, makes the actual identification.

In the case of latent examinations, perhaps the first issue that comes into play is determining the suitability of the latent fingerprint for identification. The examiner must decide if sufficient quality and quantity of the ridge detail are present in the latent print to make it possible to compare it with a known print. This determination also requires training and experience. Once a latent print is evaluated and

**CASE STUDY 13.1: THE MAYFIELD CASE**

The process of comparing latent prints to knowns has occasionally resulted in an incorrect identification, even when experienced examiners conducted the comparison. In 2004, suspected terrorists set off bombs on several commuter trains in Madrid, Spain. Spanish police recovered some latent prints from evidence believed to be closely associated with the bombers. Images of the latents were distributed internationally to law enforcement agencies in an attempt to identify them. The FBI, one of the agencies that examined the latents, searched its IAFIS files for potential matches and eventually identified one of the latents as belonging to a man named Brandon Mayfield. Mayfield lived in Portland, Oregon, and was Muslim, although he was a U.S. citizen and had been in the Army. The fingerprint identification eventually led to Mayfield's arrest. Later, it became clear that the latent print was not Mayfield's but instead came from an Algerian national named Daoud. The incident resulted in an investigation by the U.S. Department of Justice's Office of Inspector General, which issued a report in 2006. The FBI has taken steps to change and improve its internal procedures to prevent such an occurrence from happening again.

determined to be suitable for comparison, it will then be compared to the known prints on fingerprint cards. Such knowns might be obtained through an AFIS search, or the prints of certain suspects have been taken or are already on file.

The overall process an examiner uses is often abbreviated as **ACE-V**, which stands for the analysis, comparison, and evaluation that comprise the formal process followed by verification. The examiner must first analyze the latent print, determine its proper orientation, decide if there are any color reversals or other unusual circumstances, decide suitability, and then proceed to the comparison. Comparison with the known prints takes place at several levels. The overall pattern and ridge flow are first examined. Next, the **individual characteristics** (minutiae) are compared as to type of features and their locations. Finally, another level of detail consisting of pore shape, locations, numbers, and relationships, as well as the shape and size of edge features, is examined. Any unexplained difference between the known and latent prints during this process would result in the conclusion that the known is *excluded* as a source of the latent print. This is one possible outcome of the evaluation decision. If every compared feature is consistent with the known print, and there are enough features sufficiently unique when considered as a whole, then the examiner concludes **individualization**. The conclusions of one examiner should be checked by another (peer review). In general, the comparison of a latent with a known inked print could result in one of three possible conclusions: insufficient ridge detail to form a conclusion, exclusion, or individualization.

## Chapter Summary

Latent fingerprints have one of the longest histories in forensic science and continue to play a key role in many criminal cases and, increasingly, in homeland security. Fingerprints are made by the patterns found in friction ridge skin and are unique to the individual. One of the greatest challenges facing latent print examiners is the nature of latent fingerprints recovered at crime scenes. Often these are smudged, partial, or difficult to visualize. Once a print is recovered, it can be scanned and searched against national databases; this is a pattern with pattern evidence that we will see many times in subsequent chapters.

## 13.11 Review Material: Key Concepts and Questions

### 13.11.1 Key Terms and Concepts

Accidental whorl
ACE-V
Apocrine gland
Arch
Automated Fingerprint Identification System (AFIS)
Bifurcation
Biometrics
Central pocket whorl
Core
Cyanoacrylate
Delta
Development
DFO
Dot
Double loop whorl
Eccrine gland
Enhancement
Friction ridge skin
Furrows
Henry system
Hinge lifters
Individual characteristics
Individualization
Integrated Automated Fingerprint Identification System (IAFIS)
Iodine fuming
Island
Latent fingerprint
Loop
Magna Brush
Minutiae
Ninhydrin
Oblique lighting
Patent fingerprint
Physical developer (PD)
Plastic fingerprint
Powder dusting
Ridges
Ruhemann's purple
Silver nitrate
Small particle reagents (SPRs)
Super Glue®
SWGFAST
Visualization
Whorl

### 13.11.2 Review Questions

1. What is the primary value of fingerprints as evidence?
2. What are biometric identifiers? How are fingerprints related to biometric identifiers?
3. What is friction ridge skin? Where is it found on the human body?
4. Who were Herschel, Faulds, Vucetich, and Henry? Describe their contributions to fingerprint science.
5. What is AFIS? Indicate what the letters stand for, describe the system, and explain how it helps in fingerprint identification.
6. What are the three main types of fingerprints that can be found at a scene?
7. What is meant by "development" or "enhancement" of a latent fingerprint?
8. What is an example of a physical method for enhancing latent fingerprints?
9. What is an example of a chemical method for enhancing latent fingerprints?
10. Explain how you could use a laser in latent fingerprint enhancement.

11. How can a bloody fingerprint be enhanced?
12. What are systematic approaches to latent fingerprint enhancement?
13. What steps and principles are involved in fingerprint identification?
14. What does "ACE-V" mean?

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# 14
# Firearms and Tool Marks

## Chapter Overview

Both firearm and tool mark examiners use microscopic comparisons of markings to associate an item of evidence with a potential source. In the case of firearms examinations, the marks made by a firearm on a fired bullet or cartridge casing are used to determine whether the bullet or casing was fired in a particular weapon. In tool mark examinations, the microscopic features of a tool mark are used to determine whether a particular tool made the mark. What these two areas have in common is the creation of markings as a result of metal-on-metal contact. In addition to microscopic comparisons, firearms examiners conduct other examinations to further the investigation and prosecution of a crime. They examine bullets and cartridge cases to determine the make and model of the firearm that fired them, they test the functioning of firearms submitted to them for examination, they carry out serial-number restorations, and they reconstruct the circumstances of shooting incidents.

# Chapter 14
# Firearms and Tool Marks*

*Walter F. Rowe*

## Chapter Outline



## 14.1 Firearms

Before surveying the types of firearms currently being manufactured, some comments on the mechanisms of automatic and semiautomatic firearms are in order. **Automatic** and **semiautomatic weapons** function in one of three ways: **blowback**, **recoil**, or **gas piston**. In blowback weapons the fired **cartridge** pushes the **breechblock** backward against a spring; the expended cartridge is extracted by the moving breechblock and ejected from the weapon. The compressed spring then pushes the breechblock forward, removing a cartridge on the magazine and inserting

* This chapter is based on Chapter 21, "Firearm and Tool Mark Examinations," by Walter F. Rowe, as published in the third edition of this text.

**SIDEBAR 14.1. CAREER PREPARATION AND EXPECTATIONS**

Preparation for a career in the examination of firearms and tool marks is generally similar to that described in the previous chapter for fingerprints. In the past, law enforcement officers typically made the transition to the laboratory through apprenticeship with experienced examiners. Now, most positions require a college degree in a natural science for an entry-level position. A long training period and apprenticeship are still required, often accompanied by intensive training courses offered by agencies such as the U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives (www.atf.gov). Once on the job, examiners spend most of their time working in a forensic laboratory environment doing cases and continuing education.

it into the firing chamber. In the recoil operating system, the barrel of the weapon and its breechblock recoil a short distance together; the breechblock then unlocks from the barrel and continues to recoil rearward against a spring. The compressed spring returns the breechblock to its original position, loading a fresh cartridge into the firing chamber. In gas-operated weapons, a small amount of the propellant gases passes through a small hole in the barrel into a gas piston. The expanding gas forces the piston to the rear; a rod connects the piston to the breechblock so that the breechblock is also pushed to the rear. The types of firearms currently available are summarized below. (For a discussion of career preparation for this field, see Sidebar 14.1.)

### *14.1.1 Handguns*

There are two types of handguns. In a **revolver**, the cartridges are held in firing chambers in a rotating cylinder. Single-action revolvers are fired by manually cocking the **hammer** and then pulling the trigger. Cocking the hammer both rotates the cylinder to place one of the chambers under the hammer and cocks the firing mechanism. Double-action revolvers are fired by a long **trigger pull** that raises the hammer, indexes a firing chamber under the hammer, and then allows the hammer to drop, firing the cartridge. The other type of handgun is a semiautomatic pistol. These weapons are also referred to as autoloaders or self-loaders; laypersons sometimes incorrectly refer to these weapons as automatic pistols. Figure 14.1 shows a Beretta semiautomatic pistol. In semiautomatic pistols, the cartridges are held in a


***Figure 14.1*** Beretta semiautomatic pistol.

magazine (usually removable) and are loaded sequentially into the pistol from the top of the magazine. The typical firing sequence is as follows:

1. A cartridge is chambered in the pistol, usually by manually moving the slide or breechblock to the rear, then allowing it to move forward and strip the top cartridge from the magazine; simultaneously, the firing mechanism is cocked.
2. The shooter pulls the trigger, firing the cartridge.
3. Some of the energy produced by the fired cartridge is used to move the slide or breechblock to the rear, extracting the spent cartridge from the chamber, ejecting it from the weapon, and cocking the firing mechanism.
4. A spring compressed by the rearward travel of the slide or breechblock pushes the slide or breechblock forward, stripping an unfired cartridge from the magazine and loading it into the firing chamber. At the end of this cycle, the pistol is left loaded and cocked; it requires only the pull of the trigger to fire another shot.

### *14.1.2 Rifles*

These are rifled firearms designed to be held in two hands when being fired from the shoulder. There are several types of rifles available and seen in forensic laboratories. In **lever action** rifles, a lever below the weapon's receiver is dropped to move the breechblock to the rear and cock the firing mechanism. Raising the lever chambers a fresh round in the rifle. In slide or **pump action** rifles, a slide under the barrel is moved to the rear to extract and eject the expended cartridge and cock the firing mechanism; pushing the slide forward chambers a fresh round. The magazine is a tube under the barrel.

Some rifles use a **bolt action**. In a straight-pull, bolt-action rifle, the expended cartridge is extracted and ejected by drawing the bolt to the rear; moving the bolt forward strips a fresh cartridge from a magazine and inserts it into the rifle's chamber. Movement of the bolt also cocks the rifle. The turn-bolt action operates in a similar fashion except that the handle of the bolt is turned downward to lock the bolt closed. The turn-bolt action was developed to permit the firing of more powerful cartridges.

Semiautomatic rifles are analogous to semiautomatic pistols. Squeezing the trigger of a semiautomatic rifle fires one round. Some of the energy of the discharge is used to extract and eject the expended cartridge, load a fresh cartridge into the firing chamber, and cock the firing mechanism. Box magazines (either built into the weapon or detachable) are most common, although some semiautomatic rifles have drum and helical magazines. Most semiautomatic rifles operate on the gas piston principle, although blowback- and recoil-operated semiautomatic rifles are also encountered.

### *14.1.3 Other Types of Weapons*

Double rifles, or combination rifles, are sporting rifles with two rifled barrels or one rifled barrel and one shotgun barrel. The barrels may be over and under or side-by-side. Break-top actions are the most common. Shotguns are smoothbore weapons (no rifling in the barrel) commonly used to fire pellet loads rather than single projectiles. As with pistols and rifles, a variety of designs are available, including semiautomatics. Finally, there is the **assault rifle**. These are automatic weapons that fire a reduced-charge rifle cartridge. They were first developed by the Germans during

**SIDEBAR 14.2. CURRENT EVENTS: FIREARMS EXAMINATIONS IN THE INVESTIGATION OF WAR CRIMES AND HUMAN RIGHTS VIOLATIONS**

In the 20th and 21st centuries, firearms have been used in the commission of a vast number of atrocities: the 1940 Katyn Forest massacre of 4000 Polish prisoners of war by the Soviet Union, the murders of over a million Jews by Nazi *Einsatzgruppen*, the 1944 massacres of Belgian civilians and American military personnel during the Battle of the Bulge, the 1968 My Lai Massacre (in which 300 to 500 Vietnamese civilians were killed by U.S. Army troops), and the ethnic "cleansings" in the Balkans in the 1990s. In the investigation of such incidents, firearms examination can provide a wealth of useful information. The bullets and cartridges recovered at the scenes of the atrocities may of course be linked to weapons belonging or issued to specific individuals. Bullets and cartridges may also provide evidence as to who committed the atrocities. For example, an archaeological excavation of a mass grave in the Ukraine recovered numerous cartridges for German machine pistols. These artifacts confirmed that the dead were Jewish victims of one of the German execution groups that operated in the Ukraine during World War II (rather than victims of Soviet terror). The cartridges bore the dates 1939, 1940, and 1941, showing that the mass execution occurred no earlier than 1941 (when that part of the Ukraine was occupied by the German army). In this instance, the dating of the incident was of critical importance because the archaeological excavations were undertaken in support of Australian prosecutions of accused Nazi war criminals.

World War II to provide airborne troops with an automatic weapon that had better range and accuracy than the submachine gun. Modern armies have embraced the assault rifle as the principle weapon of the infantryman. The U.S. Army's M16 and the Soviet Kalashnikov AK47 are familiar examples of assault rifles. Another side of military firearms and forensic investigation is given in Sidebar 14.2.

## 14.2 Manufacture of Firearms

Firearm barrels can be rifled in a number of ways. A hook or **scrape cutter** can be used to shave away metal from the interior of the barrel to create grooves. The barrel is prepared for **rifling** by drilling out a metal bar and then reaming the interior of the barrel to smooth it. The barrel is placed on a frame, called a *rifling bench*, which rotates the barrel as the cutting tool is drawn through it. Hook cutters cut one groove of the rifling at a time; a scrape cutter that has cutting surfaces on both sides can cut two grooves at a time. After the rifling has been cut, the interior of the barrel may be polished by lapping: a soft metal plug is cast inside the barrel and then pushed up and down with rouge (a powder used to polish metal) to remove imperfections. When the rifling is complete, the raised areas are called **lands** and the cut-out channels are called **grooves**.

Most modern mass-produced firearms are rifled by **broaching**, **swaging**, **hammer forging**, or **electrochemical etching**. The etching method is similar to a technique used for serial number restoration that will be introduced shortly. When a barrel is broached, it is first drilled out to approximately the desired finished bore diameter and reamed to remove drill marks; then a gang broach (a long rod having a series of circular cutting tools on it) is forced by hydraulic pressure through the barrel. Each successive cutter on the broach cuts each groove of the rifling a little deeper until the last cutter reaches the desired groove depth. A single pass of the gang broach is sufficient to rifle a gun barrel.

When a barrel is rifled by swaging, it is drilled out to a diameter less than the desired final bore diameter, reamed to remove the drill marks, and then swaged. A rifling button is forced through the barrel, simultaneously engraving the desired rifling pattern on the inside of the barrel, expanding the barrel to the desired bore diameter, and cold-working the interior of the barrel. Cold-working hardens the interior of the barrel and permits the use of cheaper mild steel. Many inexpensive small-bore weapons are rifled by swaging.

A hammer-forged barrel is produced by first drilling out steel bar stock to a diameter larger than the desired finished bore diameter. The barrel is slipped over a hardened steel mandrel on whose surface is a negative impression of the desired rifling pattern. The barrel is hammered down on the mandrel; the mandrel is then knocked out of the barrel. Hammer forging is used to produce barrels with polygonal rifling (e.g., those of Glock® semiautomatic pistols).

Electrochemical etching is the newest method used to rifle barrels. In this process a piece of steel bar stock is drilled out, and the interior surface of the barrel is coated with strips of chemically resistant polymer. The polymer layers correspond to the lands of the rifling. A chemical etching solution is placed in the barrel and an electrode is inserted. A voltage is applied between the barrel and the electrode so that the barrel becomes the anode in an electrochemical cell. The passage of an electrical current through the cell eats away the metal on the interior of the barrel where there is no protective polymer layer, forming the grooves of the rifling. Rifling produced by **hook cutting**, scrape cutting, and broaching is often referred to as **cut rifling**. Cut rifling tends to leave more forensically useful marking inside the rifled barrel than do the other rifling methods.

The size of a firearm barrel may be designated in different ways. The most common is to specify its **caliber**, which is defined as the diameter (in hundredths or thousandths of an inch or in millimeters) of a circle that is tangent with the top of the lands of the rifling. Calibers are merely nominal; the actual bore diameter may be different. For example, a weapon designated as .45 caliber may have an actual bore diameter at the muzzle of .44 inches. The caliber of a weapon can be determined with taper gauges that are inserted into the muzzle or from a sulfur cast of the interior of the barrel. Caliber determinations should be a routine part of the examination of a firearm because the barrel may have been altered from its original caliber (by being bored out), or a barrel with a different caliber may have been fitted to a firearm (such as a .45 caliber barrel mounted on a .38 Smith & Wesson Police Special frame).

A new firearm may or may not leave a unique pattern of markings on a fired bullet. Carefully lapped barrels may have too few microscopic imperfections to produce useful patterns of markings on fired bullets. In other cases, a new barrel may have a set of unique irregularities that mark fired bullets. In the 1920s and 1930s, several studies were done on the marks produced by sequentially rifled barrels. These were found to produce unique sets of marks on fired bullets. The best explanation for this observation is that rifling tools wear during the rifling operation so that in effect each barrel is rifled with a “different” tool. A study has also examined the markings made by electrochemically etched barrels and found them to be unique. Of course, once a barrel has been used extensively it will develop its own suite of unique irregularities; in some areas, metal will have worn away (erosion), and in others minute pitting will appear due to propellant combustion residues eating away at the metal of the gun barrel (corrosion).

Cartridge cases will be marked by a number of firearm components. Firing pins will mark the primer cap of **centerfire cartridges** or the rim of the cartridge itself in **rimfire cartridges**, and the breechblock or backing plate (in revolvers) may mark the **primer** cap or even the metal of the casing itself (if the cartridge is powerful enough). In self-loading or automatic weapons, the **extractors** and **ejectors** will mark the base of the cartridge, and in weapons using magazines the lips of the magazine may also mark cartridges. Firearms examiners consequently need an understanding of how components, such as firing pins, breechblocks, extractors, and ejectors, are made. Firing pins are finished by hand filing or by turning on a lathe. Breechblocks are hand filed, milled, or turned on a lathe. Extractors and ejectors are finished by hand filing. Wherever finishing operations involve a human operator (filing, milling, or turning on a lathe), the resulting patterns of marks are unique. In some makes of firearms, the breechblock is painted so that it will not transfer markings to the primer cap.

The barrels of shotguns may be bored out of bar stock or drawn like tubing. A unique feature of shotgun barrels is the choke in the muzzle. This is commonly a constriction in the muzzle that serves to concentrate the shot pattern. Shotguns may have four degrees of **choke**: full choke (greatest choke), modified choke, improved cylinder, and cylinder-bore (no choke at all). A few shotguns have been produced with a reverse choke, which is a flaring at the muzzle intended to cause the pellet pattern to spread. The choke of a shotgun barrel may be changed using inserts or adjustable compensators. As a general rule, shotgun barrels do not leave identifiable markings on shot, **wads**, or shot columns; however, if a criminal has sawed off a shotgun's barrel (usually to facilitate concealment), metal burrs may be left at the muzzle; these may mark shot, wads, or shot columns in a unique fashion.

The diameters of shotgun barrels are customarily designated by the gauge of the shotgun. **Gauge** is defined as the number of spherical lead balls having the diameter of the interior of the barrel that weigh one pound. For example, 12 lead balls having the diameter of the interior of a 12-gauge shotgun barrel (roughly 0.75 inches) would weigh 1 pound. The only exception to this rule is the .410 gauge, whose actual bore diameter is 0.410 inches.

## 14.3 Firearm Ammunition

Figure 14.2 shows the disassembled components of a typical rifle cartridge and a shot-shell. Firearms can fire a variety of projectiles. Bullets may be lead, lead alloy, **semi-jacketed**, or **full metal jacket**. Lead bullets are soft and readily deformable. Because the surface of a lead bullet can be easily stripped off by the rifling in the gun barrel, lead bullets are used in low-velocity firearms. Because lead is a ductile and malleable metal, lead bullets are easily marked by the rifling; such bullets may also undergo extreme deformation or even fragmentation when they strike a target. Lead alloy bullets contain a small percentage of an alloying element, such as antimony in commercially manufactured bullets or tin in homemade bullets. Lead-alloy bullets are harder than lead bullets and are consequently used in weapons that have a higher **muzzle velocity**. Lead-alloy bullets are sufficiently ductile and malleable


***Figure 14.2*** Disassembled rifle cartridge and shotshell.

to be easily marked by the weapon's rifling; they also readily deform on impact. Lead and lead-alloy bullets may be plated with a thin layer of copper. The copper layer reduces the friction between the bullet and the gun barrel. This layer readily flakes off the surfaces of fired bullets, taking with it the marks made by the rifling.

Semi-jacketed bullets commonly consist of a lead core covered with a thin jacket of brass. The brass typically covers the sides of the bullet, leaving the lead core exposed at the nose (as in hollow-point bullets). **Soft-point bullets** are semi-jacketed bullets in which a soft metal plug has been inserted in the nose of the bullet. Soft-point bullets are used to hunt large game; the soft metal insert promotes expansion of the bullet when it enters the target animal. Explosive bullets are produced by inserting percussion caps in the hollowed-out noses of hollow-point bullets. The jackets of hollow-point and soft-point bullets may separate from the lead cores when the bullets enter the body of a shooting victim. Treating medical personnel or forensic pathologists must make every effort to recover the jacket because only the jacket bears markings made by the weapon's rifling. Full metal jacket bullets consist of a lead core covered with a brass jacket. The jacket covers the nose and side of the bullet and occasionally the base as well. Because the jacket of a semi-jacketed or full-metal jacket bullet is harder than lead, these bullets are not as well marked by the rifling of the gun barrel as are lead or lead alloy bullets. Moreover, semi-jacketed and full metal jacket bullets are slightly smaller in diameter than lead or lead alloy bullets of the same caliber; they also expand less upon entering the rifling. As a consequence, semi-jacketed and full metal jacket bullets may not be marked by contact with the bottoms of the grooves of the rifling.

Plastic can also be used to jacket bullets. Teflon®-coated bullets were developed for police use in barricade situations. The self-lubricating property of Teflon reduces the friction between the bullet and the barrel of the weapon and allows the bullet to reach a very high muzzle velocity. Because of their high velocities, Teflon-jacketed bullets can penetrate automobile engine blocks and also multiple plies of body armor. Nylon-clad bullets are also being marketed. Some European military forces have also produced training ammunition with plastic bullets.

Firearms examiners may also encounter a number of unusual or special purpose bullets. These include **frangible bullets** and open tubular rounds. Frangible bullets consist of iron or copper particles; the particles are simply pressed together or held together with an organic binder. Frangible bullets are used in shooting galleries and also for killing livestock in slaughterhouses.

Bullets are produced in a variety of shapes. **Wadcutter** bullets are flat-nosed, cylindrical bullets used for target shooting. Bullets may have round noses or may be pointed to reduce aerodynamic drag or to facilitate target penetration. Hollow-point bullets have depressions in their noses: hollow points facilitate expansion of the bullets when they enter tissue. The bases of bullets may be flat or they may be boat-tailed to reduce the turbulent wake of the bullet that contributes to drag. Bullets may have knurled grooves called **cannelures** engraved around their circumferences. Cannelures may contain lubricant, and the mouth of the cartridge may also be crimped into the bullet's cannelure to hold the bullet in the cartridge. Cartridge casings may also have cannelures. The cannelures in cartridges prevent the bullet from being accidentally pushed into the casing.

Cartridges may be either rimfire or centerfire. Rimfire cartridges have the primer composition in the rolled rim of the cartridge. These cartridges are fired by the weapon's firing pin striking the cartridge rim. A centerfire cartridge has a primer cap placed in the center of the cartridge base. Centerfire cartridges are produced in a wide range of shapes. These cartridges may be straight-sided or bottle-necked. The cartridges may be belted, rimmed, semi-rimmed, rimless, or rebated (with the cartridge base slightly recessed from the sides). The shape of the cartridge reflects the shape of the weapon's firing chamber.

Shotguns can fire a variety of projectiles. The most common type of projectile is shot. Shot may be made of lead, lead alloy (chilled shot), or steel. The smaller shot sizes are produced by allowing molten metal to fall through the air down a shot tower. The molten metal separates into spheres of varying diameter that cool and harden as they fall. The hardened shot is then sorted according to size and loaded into shotshells. The larger shot sizes (e.g., 00 buckshot) are individually molded. Modern shotshells are plastic with brass bases. A plastic or fiber disk, called a wad, separates the shot in the shotshell from the powder. A second wad may be placed over the shot and the mouth of the shotshell crimped over it to seal the shotshell. The shot may be enclosed in a plastic cup that protects the shot from deformation due to contact with the inside of the shotgun barrel. In some shotshells the over-powder wad and the cup may be combined into a one-piece shot column. Wads and shot columns can act as secondary projectiles and may be recovered from within close-range shotgun wounds; they may also inflict superficial injuries adjacent to shotgun wounds. Shotguns can also fire loads containing a single large-caliber round ball or a single rifled slug. Foster-rifled shotgun slugs are round-nosed conical lead bullets with hollow bases and projecting fins on their sides. The fins are set at an angle so that when a rifled slug is fired it acquires a spin. If the shotgun barrel is choke-bored, the fins are forced into the hollow base as the slug exits the shotgun muzzle.

The base of a cartridge and shotshell (called the **headstamp**) bears information such as the vendor of the ammunition (usually abbreviated, as F for Federal, Rem for Remington, R-P for Remington–Peters, or WIN for Winchester) and the gauge or caliber. The caliber or cartridge type may also be indicated in the headstamp; for example, ".30–06" means that the cartridge is a type of .30 caliber bottleneck cartridge introduced in 1906. The headstamp may also consist of a logo (e.g., a diamond on .22 caliber Winchester rimfire cartridges). Figure 14.3 shows a selection of cartridge headstamps. (Also see Case Study 14.1.)

## 14.4 Firearm Propellants and Powders

Modern **smokeless powders** may be **single base**, **double base,** or **triple base**. In single-base smokeless powders, **nitrocellulose** is the only energetic material. Double-base powders contain nitrocellulose and **nitroglycerin**, while triple-base

***Figure 14.3*** Examples of cartridge headstamps.

powders contain nitrocellulose, nitroglycerin, and **nitroguanidine**. Triple-base smokeless powders are used only as propellants in artillery ammunition. The nitrocellulose used in smokeless powders is produced by the nitration of wood pulp or cotton lint. Gun propellant grades of nitrocellulose have degrees of nitration between 13.15 and 13.25%. During the production of nitrocellulose, other characteristics, such as viscosity, particle size, purity, and stability, are carefully controlled. Scrap nitrocellulose and obsolete propellants are also used as sources of nitrocellulose. Obsolete propellant is recycled in this fashion because it is virtually impossible to dispose of such material. It cannot be burned without producing air pollutants, and few landfills will accept quantities of smokeless powder.

### CASE STUDY 14.1: APPLICATION OF FIREARMS EVIDENCE

Police were summoned to the apartment of two women where a shooting had occurred. One of the women was found dead of a perforating (through and through) gunshot wound of the chest. The decedent was wearing a short dressing gown at the time of the shooting. The other woman claimed that she and the decedent had had a lovers' quarrel and that she (the survivor) had attempted to commit suicide with a .22-caliber pistol. A struggle for the gun had ensued, during which the pistol accidentally discharged, killing the decedent instantly. An examination of the garment worn by the decedent revealed two bullet holes: one with bullet wipe under the left arm and a second in the right chest area. No gunshot residue was found either by a visual examination or by chemical tests. Test firings of the .22-caliber pistol with ammunition from the same lot as that with which the pistol was loaded at the time of the fatal shooting showed that the combination of pistol and ammunition produced visible gunshot residue deposits out to a range of 25 inches. Several conclusions could be drawn from these observations. First, the fatal bullet traveled in a left-to-right direction through the victim's chest. Second, the shot was fired from a range greater than 25 inches—a distance greater than the average adult woman's arm length. It was, therefore, highly unlikely that the decedent was struggling for control of the pistol. The surviving woman was charged with murder and subsequently convicted.

Nitroglycerin is manufactured by nitration of natural or synthetic glycerin. Nitroglycerin is considered an energetic plasticizer. It softens the propellant granules, raises their energy content, and reduces their absorption of moisture. Smokeless powders used in small-caliber ammunition typically contain a variety of other ingredients: stabilizers, plasticizers, flash suppressants, deterrents, dyes, opacifiers, graphite glaze, and ignition aid coatings. **Stabilizers** react with the acidic breakdown products of nitrocellulose and nitroglycerin (primarily the nitrogen oxides NO and $NO_2$). Diphenylamine is used as a stabilizer in single-base powder and in double-base powder with a nitroglycerin content of 20% or less. Ethyl centralite is used as the stabilizer in double-base powders with nitroglycerin contents greater than 20%. Typical stabilizer concentrations range from 0.5 to 1.5%. Plasticizers soften the propellant granules and reduce the absorption of moisture.

Other plasticizers, such as ethyl centralite, dibutyl phthalate, dinitrotoluene, and triacetin, may also be used. **Flash suppressants** interrupt the free-radical chain reactions in the muzzle gases. Muzzle gases contain high concentrations of carbon monoxide, which can react with atmospheric oxygen. Low concentrations (0.5 to 2.5%) of alkali salts, such as potassium nitrate and potassium sulfate, are used as flash suppressants. Flash suppressants may be present within the powder particles or coated on them; flash suppressants may also be added to the smokeless powder as separate particles.

**Deterrents** are coatings on propellant grains that reduce their initial burning rate. The reduction in the initial burning rate broadens the pressure peak and increases the muzzle velocity. Deterrent coatings are either penetrating or inhibiting. Penetrating deterrents include ethyl or methyl centralite, dibutyl phthalate, and dinitrotoluene. The main inhibiting ("candy shell") deterrent is Vinsol® resin. Deterrent concentrations range from 1 to 10%. Dyes are added to powder grains to facilitate brand identification (e.g., Red Dot® and Blue Dot® smokeless powders). **Opacifiers** prevent radiant energy from penetrating the surface of the powder grains (and initiating burning within the grains). Carbon black is the most commonly used opacifier. Graphite glaze reduces sensitivity to static electricity, improves the flow of powder grains, and improves the packing density of the powder. An ignition aid coating improves the oxygen balance of the surfaces of the powder grains. Potassium nitrate is the most commonly used ignition aid coating.

The manufacturer of smokeless powder controls a number of characteristics of the powder. The energy of the powder is determined by the formulation of powder (i.e., whether the powder is single base or double base); it is primarily a function of the flame temperature and the average molecular weight of the muzzle gases. The linear burning rate depends on the composition and on the porosity of the powder grains. The surface area of the powder grain is determined by its geometry. Powder grains may be spheres, cylinders, disks, or flakes; the grains may also be perforated. The surface area of the powder grains is the major control factor that the manufacturer uses to adjust the performance of a smokeless-powder product.

Smokeless powders are produced by one of two processes: the **extruded powder** process and the **ball powder** process. In the extruded powder process, the nitrocellulose and other ingredients are kneaded together with an organic solvent to form a dough-like mass. The dough is extruded through small openings in a steel die. A rotating blade cuts off lengths of extruded dough. The dimensions of the extruded grains are controlled by the size of the openings in the die, by the rate of extrusion, and by the speed of the cutting blade. The extruded powder grains are then coated and glazed with graphite. After drying to remove the solvent, the powder grains are screened to remove grains that are too large or too small. In the ball powder process, the nitrocellulose and other ingredients are mixed with solvent to make a lacquer. The lacquer is extruded through a steel die into hot water, where the nitrocellulose forms spherical grains. The solvent is removed by the hot water, and the grains are allowed to harden. The spherical grains are sorted by size, and particles in the desired size range are subjected to further processing. The grains are coated and may be passed between rollers to flatten them into disks or flakes. In both processes, the final product is a mixture of several batches of smokeless powder. The batches are blended to create a powder with a specified burning rate.

## 14.5 Collection of Firearms-Related Evidence

Fired bullets may be difficult to recover at the scenes of crimes. They may be embedded in walls, ceilings, door frames, window frames, and the like. Only rubber-coated or heavily taped tools should be used either to probe for bullets or to extract them. It is generally best for the investigator to remove the section of the building structure that contains the bullet so that the forensic firearms examiner can carefully remove the bullet in the laboratory. Some police agencies recommend that bullets be marked for identification by investigators on the nose or on the base. Under no circumstances should such identification marks be placed on top of potentially useful markings on the bullet. Care must also be taken not to dislodge any trace evidence that may be on the bullet surface. As an alternative to marking the bullet for identification, some law enforcement agencies recommend placing the bullet in a sealed pillbox or plastic vial; the container and its seal are then marked for identification. An expended cartridge can be marked for identification inside its mouth. Some agencies recommend not marking expended cartridges but rather placing them in sealed and marked containers.

The serial numbers of all firearms seized should be recorded by investigators. Investigators will generally mark firearms for identification only if they are being collected as evidence. Even then some common sense is in order; antique or highly engraved firearms should be carefully marked so their value is not diminished. All removable parts of a firearm that can mark a fired bullet or cartridge should be marked for identification. Thus, a 9-millimeter semiautomatic pistol should be marked on the barrel, the slide, the receiver, and the magazine. A revolver having an interchangeable cylinder and removable barrel should be marked on the cylinder, barrel, and frame. Weapons with removable bolts should be marked on the bolt, barrel, and frame.

For safety, loaded weapons should be unloaded before they are transported to the firearms laboratory. Magazines or clips should be carefully removed and marked for identification; live or expended cartridges should be removed from the firing chamber. Revolvers present a special problem. The investigator should scratch a small arrow on the rear face of the cylinder to indicate the chamber that was under the hammer when the revolver was collected as evidence. The chambers in the cylinder are numbered in a clockwise manner (when viewed from the rear) with chamber #1 being the chamber under the hammer. Each chamber is then emptied, with the live or expended cartridge or its container marked with the number of the chamber. In general, firearms should not be cleaned before they are shipped to the forensic science laboratory. If the firearm is to be processed for latent fingerprints, it should not be covered, but should be placed in a box or other container so that any latent fingerprints are not rubbed off by contact with the packaging.

All ammunition in the possession of a suspect in a shooting case should also be seized as evidence. The firearms examiner may have to estimate the range of fire from a powder pattern or shotgun pellet pattern. Such estimation requires ammunition from the same batch as that which produced the questioned powder or pellet pattern. Live ammunition cannot be sent through the U.S. mail; therefore, the investigator may have to hand-carry live ammunition unloaded from a weapon or seized from a suspect to the forensic science laboratory or ship it through a private parcel service.

## 14.6 Laboratory and Forensic Examinations of Firearms Evidence

### *14.6.1 Microscopic Examinations*

Figure 14.4 shows examples of fired bullets that might be submitted as evidence. Several of them show patterned markings or trace evidence. Bullets should always be examined for the presence of trace evidence as well as patterned markings. Bullets may pick up textile fibers, traces of paint, or bits of concrete and brick from intermediate targets. Bullets may acquire patterned markings from clothing or window screens. In one case, a state police officer was shot during a traffic stop. One bullet passed through the badge device on his uniform cap. When recovered, the bullet had the pattern of the badge embossed on its nose. In another case, a man was accused of shooting his neighbor to death. The defendant claimed that he had shot the victim during a quarrel in the victim's kitchen during which the victim had attacked him. The discovery of an impression on the nose of the fatal bullet that matched the window screen in the victim's kitchen window (along with an apparent bullet hole in the screen) refuted the self-defense claim.

The goal of the initial examination of a fired bullet is the determination of general rifling characteristics of the firearm that fired it. This information allows the forensic firearms examiner to narrow the possible makes and models of firearms that could have fired the bullet. The general rifling characteristics to be determined are


***Figure 14.4*** Expended bullets that might be submitted for firearms examination. (A) Deformed full metal jacket bullets. (B) Core and detached jacket of hollow-point semijacketed bullet. (C) Lead-alloy bullet that struck body armor. (D) Lead-alloy bullet that passed through window (note embedded glass particles). (F) Lead-alloy bullets that passed through plywood (note embedded wood fibers).

- Caliber
- Number of lands and grooves
- Direction of twist of the rifling
- Degree of twist of the rifling
- Widths of lands and grooves

The caliber of a fired bullet can be determined in a variety of ways. If the bullet is not deformed, its diameter can be measured with a micrometer, or it can be compared with bullets fired from weapons whose caliber is known (i.e., so-called fired standards). With either method, allowance must be made for the fact that lead and lead-alloy bullets are larger in diameter than full-metal jacket or semi-jacketed bullets of the same nominal caliber. If a bullet is severely deformed, its possible caliber may be determined by weighing it. The weight of the bullet will rarely pinpoint its caliber but will serve to eliminate a number of calibers from consideration. For example, a 72-grain bullet may be .32 caliber but it cannot be .22 caliber. If the bullet is fragmented, its possible caliber can be determined by combining the measured width of a land marking with that of an adjacent groove. Tables of combined land and groove widths have been prepared for a number of makes and models of firearms.

The number of lands and grooves is determined by inspection, as is the direction of twist of the rifling. Rifled firearms have either right-twist (Smith & Wesson type) rifling or left-twist (Colt type) rifling. The degree of twist of the rifling and the widths of the lands and grooves can be determined by microscopic measurements of the rifling marks on the bullet. However, it is generally simpler to compare the questioned bullet to a set of fired standards—bullets fired from firearms having known rifling characteristics. The general rifling characteristics determined from a fired bullet can be used to search a database such as that prepared by the Federal Bureau of Investigation (FBI). Both a text form and a computer-searchable form of the database can be downloaded from the Internet.

Class characteristics of firearms can also be determined from expended cartridges. The significant class characteristics are

- Caliber
- Shape of firing chamber
- Location of the firing pin
- Size and shape of the firing pin
- Size of extractors and ejectors (if any)
- Geometrical relationship of the extractor and ejector

For the most part, these characteristics can be determined by inspection. Determination of the caliber and the size of the firing pin and extractor requires the use of a micrometer or a microscope equipped with a reticule for measurements. The class characteristics can be used to search the FBI database for matching makes and models of firearms.

Some care should be exercised in inferring the general class characteristics of a weapon from fired bullet or cartridge cases. A number of devices are available that permit the firing of types of ammunition other than that for which the weapon was designed. For example, crescent-shaped metal clips can hold rimless pistol cartridges in the cylinder of a revolver. A barrel insert can convert a shotgun into a rifle. Subcaliber cartridges can be wrapped in layers of paper to facilitate loading into the cylinder of a revolver. It may even be possible to chamber and fire a larger caliber cartridge in a weapon. Rifling characteristics of barrels can be altered by re-boring them.

If a questioned firearm has also been submitted in a case, the forensic firearms examiner should conduct an initial examination for trace evidence that might be destroyed in the course of his or her testing; for example, blood or other tissue may have been blown back from a contact gunshot wound onto the exterior of the weapon or inside the barrel. There may be textile fibers on the weapon from the shooter's pants or jacket pocket. The weapon should also be processed for latent fingerprints before additional tests are undertaken. Next, the firearms examiner determines if the weapon's class characteristics are consistent with those found on the fired bullets or cartridges. Taper gauges can be used to verify the weapon's caliber; the number and lands and grooves and their direction and degree of twist can be determined with a **helixometer**. A sulfur cast of the interior of the barrel may also be used to determine all general rifling characteristics.

Once it has been determined that the class characteristics of the firearm and those of the fired bullets or cartridges are consistent, the weapon must be test fired to obtain bullets and cartridges for comparative microscopic examination. Before the weapon is test fired, the examiner conducts examinations to determine if the firearm's mechanism operates properly and if the weapon can be safely fired. These examinations are discussed below. If the weapon cannot be safely fired, the examiner may be able to replace damaged or missing parts from the laboratory's firearm collection.

To obtain test-fired bullets, the firearm is fired into a bullet trap. Most firearms laboratories use some type of water trap to catch fired bullets. A horizontal bullet trap consists of a steel tank filled with water. The firearms examiner fires the test shots through a self-sealing rubber membrane. After the test shots have been fired, the tank is opened and the fired bullets removed for subsequent microscopic analysis. A vertical bullet trap does not require a self-sealing membrane. A basket at the bottom of the tank is used to recover the test-fired bullets.

Bullets are mounted for microscopic comparison on a comparison microscope. A comparison microscope consists of two compound microscopes connected by an optical bridge. It allows two specimens to be viewed side by side. Some examiners recommend first comparing the test-fired bullets with each other to verify that the weapon's barrel consistently marks the bullets fired through it. If consistent marking does not occur (e.g., if the barrel is severely rusted), further comparison of the questioned bullets and the test-fired bullets would be a waste of time. The comparison process is straightforward, albeit tedious. The examiner searches the surface of one bullet for a distinctive pattern of parallel **striations** and then rotates the other bullet slowly in an attempt to find a matching pattern. If a matching pattern is found, the bullets will be slowly rotated together to see if additional matching patterns of striations can be found. If no matching pattern is found, the examiner tries to find another distinctive pattern of striations on the first bullet and again tries to find a matching pattern on the second bullet. This process continues until matching striation patterns are found or the examiner exhausts all the distinctive striation patterns on the first bullet. Before the two bullets can be said to match, most firearms examiners require that identical patterns of three or more consecutive striations be found on each bullet. Not all striations on the two bullets must match. Particles of dirt in the weapon's barrel may have made stray markings on the bullets, or the two bullets may have entered the rifling in slightly different ways. Figure 14.5 shows matching striation patterns within the land impressions of two bullets fired from the same semiautomatic pistol. Striation patterns in the groove impressions can also be examined; however, jacketed and semi-jacketed bullets may not expand sufficiently to fill the groove of the rifling.

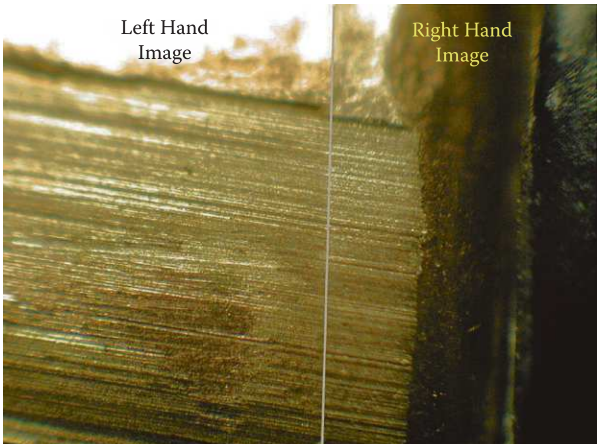


***Figure 14.5*** Microscopic comparison of striations in the land markings of two bullets fired from the same semiautomatic pistol.

Other markings on bullets have also been compared from time to time. **Skid marks** are marks parallel to the axis of the bullet made when the bullet initially enters the rifling; the edges and surfaces of the lands will scrape along the bullet surface before the bullet is fully gripped by the rifling. The term skid mark is also applied to marks near the nose of a bullet caused by contact with the **forcing cone** in the barrel of a revolver. The forcing cone is a flare at the breech end of a revolver barrel that is intended to guide the bullet into the rifling. Skid marks made by the forcing cone of a revolver are hard to reproduce; a number of bullets might have to be test fired before one strikes the same spot on the forcing cone as the questioned bullet. **Slippage** marks are made on a bullet when it slips along the tops of the lands without being gripped by the rifling. Slippage marks are the result of the barrel being worn or having been bored out. Slippage marks may also result if a sub-caliber bullet is fired in a weapon. Slippage marks are hard to replicate in test firings.

A variety of markings on cartridges can be compared microscopically. There is a logical hierarchy to follow in conducting such comparisons. **Firing pin impressions** and breechblock markings (also called **bolt-face signatures**) should be compared first because they can only be produced by firing a cartridge in a firearm. Figure 14.6 shows the microscopic comparison of firing pin impressions on two cartridges fired from the same semiautomatic pistol. Chambering, extractor, ejector, and magazine marks may be made by loading a cartridge in a weapon without firing it.

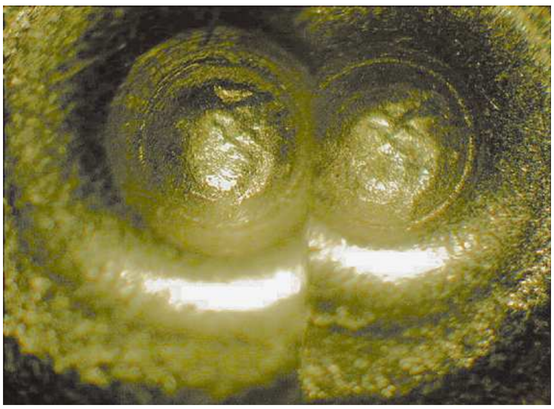

***Figure 14.6*** Microscopic comparison of firing pin impressions on two cartridges fired from the same semiautomatic pistol.

The following conclusions may be reached as a result of the comparison of bullets or cartridges:

- *A positive identification*—The class characteristics are consistent and individual characteristics match. This means that the likelihood that a firearm other than the firearm submitted for examination fired the questioned bullet or cartridge is so remote that it must be regarded as a practical impossibility.
- *Negative identification*—The questioned bullet or cartridge was not fired in the submitted weapon. This means that the class characteristics did not match. In this instance no microscopic comparison will have been undertaken.
- *Inconclusive*—This means either that there was too little information on which to base a conclusion or that, although the class characteristics matched, sufficient individual characteristics to declare a match could not be found. The firearms examiner does not render a negative identification in this last instance because the individual characteristics of the firearm may have been altered by further use; for example, there may have been bore erosion due to firing a large number of rounds through the weapon. The weapon may also have been deliberately altered by the shooter. Some weapons (e.g., Glock pistols) do not make usable striation patterns on fired bullets.

The microscopic comparison of bullets and cartridges is a very tedious and time-consuming process. Most law enforcement agencies keep open bullet and cartridge casing files where evidence from open criminal cases is kept for later comparison with test-fired bullets and cartridges from weapons recovered in subsequent investigations. However, the time required for such comparisons is such that they are attempted only when information developed by investigators provides a link between a new case and an open case. The **National Integrated Ballistic Information Network (NIBIN)** was developed to facilitate linking firearms evidence in cases in different jurisdictions. The system consists of data-acquisition computer workstations and data-analysis computer workstations, all linked in a nationwide computer network. The data-acquisition computer workstation is used to scan and digitally capture images of bullets and cartridge cases. Each captured image has a mathematical signature that is placed in a database. Once a bullet or cartridge case is scanned and its image captured, the database can be searched for possible matches. The search of the database results in a list of potential candidate hits, and the NIBIN system operator can retrieve digitized images for visual comparison using the data-analysis computer workstation. Likely candidates for matches are referred to a firearms examiner for manual comparison of the actual items of evidence. The NIBIN system is designed to be operated by a technician with minimal skills, freeing the more highly trained firearms examiner for other duties. The image databases can be shared among firearms laboratories in different jurisdictions. The United States and Canada have agreed to share their image databases.

Two states, New York and Maryland, have legally mandated the ballistic "fingerprinting" of new firearms. Before a semiautomatic pistol can be sold in these states, a cartridge case fired in it is scanned into a special database. Theoretically, if the weapon is subsequently used in the commission of a crime, an expended cartridge case from the crime scene can be scanned by a data-acquisition computer work station and matched to the image in the database. Police investigators would then be led to the original purchaser of the handgun. After the expenditure of several million dollars, the Maryland ballistic fingerprinting program has only solved one case. In 2005, an estranged husband was convicted of the murder of his wife with a .40 caliber handgun. The gun was never recovered; however, expended cartridges recovered at the murder scene were matched to a semiautomatic handgun purchased by the defendant. The New York ballistic fingerprinting program has shown a similar record of limited success in solving shooting cases. A low hit rate for ballistic fingerprinting is to be expected, as most firearms are never used in the commission of crimes. There are also technical difficulties with the imaging and databasing systems. When California was considering a ballistic fingerprinting program similar to the Maryland and New York programs, the state attorney general commissioned a pilot feasibility study. This study revealed a high rate of misses (38%). The hardness or softness of the brass in the percussion caps of the centerfire pistol cartridges was identified as the likely culprit. If the brass is too hard, poor firing pin and breechblock impressions with limited detail result; if it is too soft, the large amount of detail in the impressions confuses the image-matching software algorithm. (See Sidebar 14.3.)

### SIDEBAR 14.3. HISTORICAL NOTE: FIREARMS EXAMINATIONS AND BATTLEFIELD ARCHAEOLOGY

Battlefield archaeology uses the methods of archaeology to reconstruct human behavior on battlefields. The distribution of artifacts such as bullets, percussion caps, and cartridges can be used to locate battlefields (if the precise location of an engagement is unknown or disputed), to locate troop positions on the field, to provide estimates of the numbers of weapons of a particular type used in the battle, and to chart the movements of weapons across the battlefield. Comparisons of firing pin impressions on cartridges excavated on the Little Bighorn battlefield, the scene of Custer's Last Stand, allowed archaeologists to track the movement of a particular .45 caliber 1873 Springfield cavalry carbine from the hill where the initial onslaught of the Sioux and Cheyenne warriors overwhelmed several detached companies of Custer's force to Last Stand Hill, where Custer and the remnants of his command were wiped out. Microscopic comparisons of firing pin impressions on the large number of .44 caliber Henry cartridges recovered from the field enabled archaeologists to estimate how many Henry and Winchester repeating rifles were used by the Native American participants in the battle. The Sioux and Cheyenne warriors had more repeating rifles than was previously believed, and these weapons gave them a significant firepower advantage over the troopers of the 7th Cavalry, armed with single-shot carbines and Colt revolvers.

The semi-arid environmental conditions of the American West seem to be the most conducive to the preservation of markings on soft copper percussion caps and cartridges. The most significant applications of microscopic firearms examinations have been to 19th-century Indian Wars battlefields: Cieneguilla (1854), the Fetterman Massacre (1866), and Hembrillo Canyon (1880). Bullets and cartridges recovered from battlefields sometimes provide a vivid glimpse of the last moments of a soldier's life. An expended .52 caliber cartridge excavated at the scene of the Fetterman Massacre, in which several thousand Sioux, Cheyenne, and Arapahoe warriors ambushed and killed 79 U.S. Army troops and two civilians, had two firing pin impressions made by different Spencer repeating carbines. The cartridge had misfired in one carbine and a desperate soldier had picked up the ejected cartridge and manually loaded it into another carbine

### 14.6.2 Examination of the Weapon

In addition to the microscopic examination and comparison of bullets and cartridges, firearms examiners must carry out other examinations on firearms. Before a firearm can be test fired, the examiner must verify that the weapon's action and safety devices work properly. If the weapon does not function properly, the examiner should note that fact and determine the reason for the malfunction. Critical components may be damaged or missing. Because meaningful microscopic comparisons of bullet and cartridges require that the weapon be fired, the examiner may have to replace damaged or missing components with parts taken from the forensic laboratory's firearms collection. Many firearms have both passive and active safety devices; some firearms have no safety devices. Passive safety devices are features that the shooter does not have to set. Such devices include a half-cock position for the hammers of weapons with exposed hammers, a grip safety, and a firing pin catch or block. A half-cock safety is intended to prevent the hammer from accidentally falling far enough to discharge the weapon. If the hammer is released before it is fully cocked, it will fall to the half-cock position and be stopped. A grip safety is located on the back of the grip of a handgun. It prevents the trigger of the weapon from being squeezed unless the heel of the hand has depressed the safety. A firing pin catch or block prevents the firing pin from moving forward to strike the cartridge primer until the trigger has been squeezed. This prevents the weapon from accidentally discharging if it is dropped. Active safety devices are set by the shooter; they include trigger blocks, slide blocks, and safety decocking levers.

Trigger blocks prevent the trigger from being squeezed. Slide blocks prevent the slide of a semiautomatic handgun from being drawn to the rear and also block the trigger mechanism. A safety decocking lever prevents the trigger from being squeezed and rotates the rear section of a two-part firing pin so that the hammer cannot strike it. When the safety decocking lever is set, the cocked hammer of the weapon can be lowered without risk of an accidental discharge. The safety decocking lever prevents the weapon from being fired normally and also if it is dropped. The firearms examiner must verify that the weapon's safety devices work properly for his or her own safety when test firing the weapon, and because the defendant in a shooting case may allege that the weapon discharged accidentally.

### 14.6.3 Serial Number Restoration

Often, firearms associated with crimes are stolen and the serial number has been removed by grinding. Firearms examiners are often tasked with recovering the serial number if possible. When a serial number is stamped into a metal, the structure of the metal below the stamp is compressed and the structure is weakened. Most serial number recovery techniques take advantage of this and attempt to carefully remove the damaged sections using chemical etching. These methods involve the use of acids, and the composition of the acid mixture depends on the metal in which the serial number has been stamped. Usually the first step is to polish the area of interest to a smooth finish. Chemical etching solutions are then applied and the progress is carefully monitored. The damaged areas will dissolve first, but if the process is allowed to go on for too long, the surrounding metal will also be dissolved and the serial number will be permanently obliterated. Other methods use electrochemical etching and **ultrasonic cavitation**. Ultrasonic cavitation works on a principle similar that of chemical and electrochemical etching. The surface where the serial number has been obliterated is polished as described above and then the weapon is placed in an ultrasonic bath where it is subjected to high-frequency vibrations. Minute bubbles form on the metal surface (a process called *cavitation*). Cavitation causes etching of the metal surface. This same phenomenon causes pitting of high-speed marine propellers. In serial number restoration, the etching proceeds fastest where the metal structure has been disordered by stamping the serial number.

Firearm and tool mark examiners may be called upon to restore stamped serial numbers on other items, such as automobile engine blocks. A method has also been developed for the restoration of stamped serial numbers on plastic items (e.g., camera bodies, stereos, computer equipment). Organic solvents are used to swell the plastic. Different types of plastics require the use of different organic solvents.

A serial number may be unrecoverable for a number of reasons. The filing or grinding may have removed too much metal. The criminal may overstamp the serial number with new numbers or letters or obliterate it by attacking the metal surface with a metal punch. Methods have been proposed to prevent the removal of serial numbers from weapons. According to one such idea, a laser would be used to drill holes in the weapon's frame following a grid pattern. Each digit of the serial number would be represented by a hole drilled at a specific location in the grid; the serial number could be removed only by completely removing a section of the frame. No such scheme has ever been implemented.

### *14.6.4 Range-of-Fire Estimation from Powder and Pellet Patterns*

Detailed reconstruction of shooting incidents requires knowledge of ballistics, the branch of physics that studies projectile motion. A bullet encounters different ballistic regimes on its journey from the firing chamber of the weapon to its final resting place in its target. The first regime is that of **interior ballistics**, where the chemical energy stored in the propellant is converted into the kinetic energy of the projectile. The second ballistic regime is that of **transitional ballistics**, through which the projectile passes as it moves from interior ballistics to exterior ballistics. In the transitional ballistic regime, a spinning projectile experiences both lateral and vertical jumps. In small arms, these lateral and vertical jumps are negligible. In the regime of exterior ballistics, the projectile moves under the combined effects of a number of forces such as gravity, centrifugal forces, and aerodynamic forces.

In the reconstruction of shooting incidents, the range and direction of fire are of paramount importance. Firearms examiners are frequently called upon to estimate the range from which a gunshot was fired by examining gunshot residue patterns on the victim's skin or clothing. **Gunshot residue** consists of particles from the gun barrel, particles from the bullet surface (lead, lead alloy, or brass), particles originating from the propellant (unburned or partially burned particles of smokeless powder as well as soot), and particles originating from the primer (lead, or lead, antimony, and barium). This residue is projected in a roughly conical cloud in the direction of the target. Because the gunshot residue particles are traveling through the air, they experience aerodynamic drag forces. The smaller particles are slowed more rapidly and consequently travel shorter distances than the larger particles. Some gunshot residue may also leak out of the weapon to be deposited on the shooter's hands, face, and hair. Gunshot residue may be seen on the hands of a shooting victim who is grappling for a weapon when it is fired. Revolvers in particular produce distinctive powder-burn patterns on the hands when they are gripped with the hand around the front of the cylinder.

The appearance of a gunshot wound may hold a clue to the range from which it was inflicted. Forensic pathologists usually place the range from which a gunshot wound was inflicted into one of several categories: distant shots, close-range shots, near-contact shots, and contact shots. Distant shots are fired from such a range that no detectable gunshot residue reaches the skin or clothing of the victim. The gunshot wounds inflicted by distant shots consist of a circular or elliptical defect in the skin, which is surrounded by a **marginal abrasion** or **contusion ring** where the skin has been stretched and torn by the entry of the bullet. The marginal abrasion may be overlaid by a **gray ring**, which is a ring of propellant combustion products, bullet lubricant, and metal from the bullet surface that has been wiped off onto the skin. The material comprising the gray ring is also termed **bullet wipe**. Bullet wipe may be found on any solid materials through which bullets pass, such as clothing, doors, and walls.

Close-range gunshot wounds are inflicted at ranges short enough for gunshot residue to reach the skin or clothing of the victim. Two types of gunshot residue deposition are seen with close-range shots: **stippling** (tattooing) or soot (smudging). The large propellant particles that produce stippling travel farther than the finer particles that comprise the soot. Consequently, as the range of fire for close-range shots decreases, the resulting gunshot residue patterns go from widely dispersed stippling to more concentrated stippling plus soot.

At a near-contact range, stippling and smudging are concentrated in a tight circle. The weapon's muzzle flash may tear clothing and char or melt clothing fibers. Woven fabrics typically tear apart along the warp and weft directions, producing a cruciate (cross-like) defect; knit fabrics usually show a circular area of damage. Natural fibers, such as cotton and wool, are charred by the muzzle flash, whereas manmade fibers are usually melted. If the gunshot wound is inflicted on a part of the body that is covered with hair, the hair will show characteristic singeing.

Loose-contact gunshots are fired with the weapon's muzzle just touching the target surface. Gunshot residue may be blown outward between layers of clothing. The muzzle flash will produce effects similar to those observed in near-contact gunshots. Tight-contact gunshots over bony plates, such as the vault of the skull or the sternum, produce a characteristic **stellate defect**: an irregular, blown-out entrance wound. This type of wound is caused by the propellant gases separating the soft tissue from the bone and creating a temporary pocket of hot gas between the bone and the muzzle of the weapon. If the gas pressure is high enough, the soft tissue and skin will tear, creating a jagged entrance wound. Blood and other tissue may be blown back into the muzzle of the weapon and onto the hand and forearm of the shooter. Firearms examiners should always check weapons for such trace evidence. The soft tissue may be forced back against the muzzle of the weapon hard enough to receive a muzzle impression. Carbon monoxide in the muzzle gases may also react with blood in the wound area to produce carboxyhemoglobin.

Determination of the range of fire from a gunshot residue pattern requires the original powder pattern, the firearm used to fire the pattern, ammunition from the same lot as that used to fire the pattern, and knowledge of the weather conditions at the time of the shooting. If the original powder pattern is on a garment, its preservation for examination is straightforward. The powder pattern may require chemical treatment or special imaging techniques to render it visible, particularly if the pattern is on dark-colored or blood-soaked clothing. If the powder pattern is on the victim's skin, scaled photographs may be the best method for preservation of the original powder pattern. When the victim is deceased, the skin bearing the powder pattern may be excised and treated with preservatives; however, skin treated in this way may shrink or stretch, altering the dimensions of the powder pattern. The court may regard excised tissue as unnecessarily inflammatory evidence and consequently exclude it at trial. Some religious groups would regard the removal and preservation of a portion of the victim's body as extremely sacrilegious.

Determination of the range of fire from a powder pattern requires that the firearms examiner test fire powder patterns at various ranges until he or she is able to reproduce the original pattern in size and density of gunshot residue deposition. For the results of the tests to be meaningful, the firearms examiner must use the same weapon and ammunition as that used to fire the original pattern. The same weapon must be used because weapons vary in their leakage of gunshot residue. A weapon with a worn barrel, for example, might produce more gunshot residue than a weapon of the same type with a pristine barrel. Using ammunition from the same lot is likewise important. Ammunition manufacturers commonly change lot numbers when they exhaust a lot of one of the components (bullets, casings, primers, or propellant). Using ammunition from the same lot, therefore, ensures that critical components, such as primers and propellant, are the same for the questioned powder patterns and the test-fired patterns. If police investigators seized any ammunition with the firearm, it may be used to fire the test patterns.

Weather conditions also affect the dispersal of gunshot residue. Wind and rain may disperse the plume of gunshot residue so that little or no residue reaches the surface of the target, even at very close range. Ambient temperature also affects the rate of burning of smokeless powder. While the effect of temperature on powder patterns has not been demonstrated, research has shown that temperature does affect the dispersal of shotgun pellets. Duplication of the weather conditions may not be feasible; in such a case, it may not be possible to estimate the range of fire.

Firearms examiners may need to use special techniques to visualize gunshot residue patterns on dark or bloodstained clothing. Infrared imaging technologies have proven to be useful for visualizing gunshot residue patterns obscured by blood. The hemoglobin and other proteins in blood are relatively transparent to certain wavelengths of infrared radiation, while graphite-coated propellant particles and soot strongly absorb infrared radiation. Chemical methods for visualizing gunshot residue patterns are also widely used, most commonly the **Griess test** and **Maiti test** which react with nitrites ($NO_2^-$ ions). The Griess reagent will not react with inorganic nitrates or with the cellulose nitrate in the partially burned or completely unburned smokeless powder particles in the powder pattern. The Maiti test is an alternative test for the presence of nitrites in a gunshot residue pattern.

Other color tests are commonly used in conjunction with the Griess test or Maiti test. The **sodium rhodizonate** test is used to visualize the dispersal of lead (primarily from the cartridge primer) in the gunshot residue pattern. Lead residues are transferred from a garment to filter paper by pressing. The filter paper is then sprayed either with an aqueous acid buffer solution (pH 2.8) followed by a saturated aqueous sodium rhodizonate solution or with a solution of sodium rhodizonate saturated in pH 2.8 aqueous buffer. A scarlet color appears immediately if lead is present. To avoid false positives from other non-lead inorganic materials, the filter paper should be blotted with clean filter paper and dried with a hair dryer. The filter paper is then sprayed with 5% aqueous hydrochloric acid until the scarlet color is converted to blue. If the filter paper is again blotted with clean filter paper and dried with a hair dryer, the blue color may be preserved indefinitely. If the garment is light colored, the sodium rhodizonate reagent can be sprayed directly on it. Figure 14.7 shows powder patterns that have been enhanced by sodium rhodizonate and also by the Griess test.

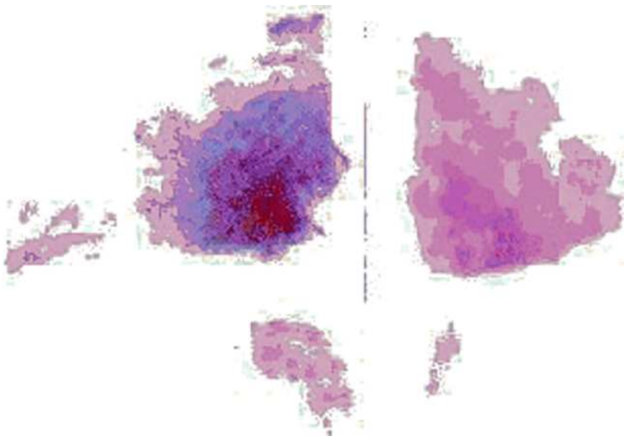

***Figure 14.7*** Powder patterns treated with sodium rhodizonate (upper patterns) and modified Griess reagent (lower patterns). Patterns on the left are as originally test fired; patterns on the right have been laundered.

Firearms examiners also estimate ranges of fire from shotgun pellet patterns. When a shotgun is fired, the pellet mass spreads laterally. Thus, pellet patterns fired at different ranges have different sizes and different shot densities. A widely used rule of thumb is that the pellets spread 1 inch laterally for each yard down range. In order to determine the range of fire from a shotgun pellet pattern, the firearms examiner needs the original pellet pattern, the shotgun used to fire the pattern, ammunition from the same lot as that used to fire the pellet pattern, and a knowledge of the weather conditions at the time of the shooting. Typically, the firearms examiner then test fires the shotgun at various ranges until he or she obtains a pellet pattern similar in size and pellet density to the questioned pattern. It is also possible to use regression analysis to determine the range of fire and its confidence limits. If regression analysis is used, the firearms examiner must use some measure of the size of the pellet pattern.

The sizes of shotgun pellet patterns are affected by the choke of the shotgun barrel. Full-choke barrels fire smaller, denser pellet patterns than cylinder-bored barrels (i.e., barrels without any choke). Double-barreled shotguns often have barrels with different chokes. A number of barrel inserts and adjustable compensators can also be placed in a shotgun barrel to change its choke. Thus, a firearms examiner may have to test fire pellet patterns using both barrels of a double-barreled shotgun and make a range of fire estimates for both barrels. Likewise, if the shotgun has an adjustable compensator, the firearms examiner should test fire pellet patterns for the extreme settings of the compensator (greatest choke and least choke) and make range-of-fire determinations for both settings.

Sawing off the barrel of a shotgun may increase the size of the pellet patterns it will fire; however, this phenomenon depends on the type of shotshells fired. With some types of shotshell, little or no spreading is seen, even when the barrel is shortened to 6 inches. The size of a shotgun pellet pattern can also be affected by the presence of an intermediate target (such as a window, window screen, or door). If the mass of shotgun pellets encounters a target that slows down the leading pellets in the mass, the trailing pellets will overtake and collide with them. The leading pellets will be deflected on new trajectories so that the pellet pattern produced in the final target will be larger than would be the case in the absence of the intermediate target. The shotgun pellets may be marked by the intermediate target or pick up trace evidence from it.

### 14.6.5 Trajectory Studies

The direction of fire can be determined from a variety of phenomena. It can obviously be determined from the locations of entrance and exit wounds (with due allowance for the possible deflection of the bullet by bone). If the bullet passes through a bony plate, such as the vault of the skull, it will punch out a cone-shaped hole. The wider end of the cone indicates the direction the bullet was traveling. Coning or beveling is observed not only with bone but also with glass, wallboard, and wood. If a bullet strikes a long bone, such as a femur, it will punch out a wedge-shaped segment of bone; the wedge will be displaced in the direction the bullet traveled.

The paths of bullets are also frequently reconstructed at crime scenes. Because most shootings take place at short ranges, the paths of the bullets can be approximated by straight lines. An accurate reconstruction of the path of a bullet requires that the bullet mark two fixed objects within the crime scene. For example, a bullet might pass through (or perforate) the wall of a room, leaving an entrance hole (sometimes referred to as the in-shoot defect) in the wallboard on one side and an exit hole (or out-shoot defect) on the other. Rods, strings, or laser beams can be centered in each of the two holes to approximate the bullet's path. The farther apart the in-shoot and out-shoot defects are, the more accurate the reconstruction will be. If the bullet makes only a single hole at the crime scene, the bullet's angle of impact can be estimated from the shape of the bullet hole. For an elliptical bullet, the ratio of the width of the hole to its length is approximately the sine of the angle of impact. This is the same method used to determine the angle of impact of a blood drop and is subject to the same uncertainties. Even if the path of the bullet cannot be accurately determined, it may be possible to define the general area that the bullet came from and limit the area that must be searched for expended cartridge cases and other evidence of the shooter. If a bullet came through an open window to strike a victim, all locations from which a fired shot would not reach the window can be eliminated as locations of the shooter. Suppliers of crime scene processing equipment now often also sell materials for bullet trajectory reconstruction. Bullets may be deflected from their trajectories by ricochet. When a bullet strikes a target it penetrates the target, disintegrates upon impact, or ricochets. Ricochets can occur from any surface, including water. For any particular target surface, there is a critical angle of incidence below which bullets will ricochet from the surface. For most surfaces, this angle is around 5 or 6 degrees. The angle of ricochet is generally less than the angle of impact. Bullet shape and composition also affect whether ricochet will occur. Round-nosed bullets are more likely to ricochet than pointed bullets, and full metal jacket bullets are more likely to ricochet than semi-jacketed bullets or lead and lead-alloy bullets. A ricochet causes a bullet to lose much of its kinetic energy so that it is more likely to inflict a penetrating rather than a perforating wound. Ricochet also upsets the yaw angle of the bullet so that it may produce a key-hole wound. A ricocheting bullet may pick up trace evidence, such as particles of concrete or brick, from the surface from which it ricochets.

## 14.7 Tool Marks

With firearms, we are concerned with markings including those made by the barrel rifling on bullets, firing pin impressions, and breech face markings. Tool mark analysis is similar in that we are interested in the marks made on or in a material by some type of tool. An example would be a mark left by a screwdriver on a metal window frame. The concept of comparison is similar in both cases.

### 14.7.1 Types of Tool Marks

The three categories of tool marks are **compression** (or indented) **tool marks**, **sliding tool marks**, and **cutting tool marks**. Compression tool marks result when a tool is pressed into a softer material. Such marks often show the outline of the working surface of the tool, so class characteristics of the tool (such as dimensions) can be determined. The individual characteristics of the tool may be more difficult to discern in compression tool marks. Sliding tool marks are created when a tool slides along a surface; such marks usually consist of a pattern of parallel striations. Class characteristics are more difficult to determine from sliding tool marks; for example, screwdrivers, chisels, and pry bars could all make very similar sliding marks. Cutting tool marks are a combination of compression and sliding tool marks. The cutting tool indents the material being cut and, as it does so, the working surfaces of the tool slide over the cut surface.

The quality of a tool mark is very much affected by its substrate, the material on which the tool mark is made. In general, soft metals such as lead, copper, and brass are excellent recipients of tool marks. Many plastics are good surfaces for the retention of tool marks. Painted surfaces are also excellent substrates for tool marks because paint layers consist of a plastic vehicle or binder in which pigment particles are dispersed. Other surfaces, such as raw wood and hard metal, are poor substrates for tool marks. Raw wood is a poor substrate for sliding tool marks because its grain structure has the same dimensions as the striations in the typical tool mark. Hard metal surfaces are poor recipients of tool marks because their hardness prevents them from being marked by tools.

### 14.7.2 Processing Tool Marks at Crime Scenes

Tool marks may be found on a variety of surfaces. Points of entry such as doors and windows should be examined for pry marks. Doors of safes and cabinets may also show pry marks. Cutting tool marks may be found on lock hasps, chains, and chain-link fences. Once a tool mark is found, the crime scene technician must take care to prevent alteration of the mark. In particular, he or she should make sure that no one attempts to fit a suspect tool into a tool mark; to do so risks alteration of the mark and would vitiate the value of any transferred trace evidence on the tool.

Safe burglaries in particular provide a wealth of tool marks. Safes may be broken into in a variety of ways. For example, safes may be broken open with a cutting torch. Although the cutting torch itself leaves no tool marks on the safe, there may be cutting tool marks on the hoses used to connect the oxygen and acetylene tanks to the cutting torch. Lightweight safes used in the home or by small businesses can be opened by prying open the door. This will leave tool marks on the edge of the door and the adjacent frame. The front plate of the safe door can be peeled away by insertion of a pry bar or similar tool between the front plate and the door's frame. Once the front plate is peeled away from the frame, the locking bars in the safe door may be forced back with the pry bar. In this case, tool marks will be found on the front plate and the locking mechanism. A hole may be pounded or chopped through the cladding of the safe. Two areas are usually attacked: the bottom or the front plate adjacent to the lock. If the bottom is the site of attack, a hole will be pounded through into the safe and the valuables extracted through the hole. If the front plate is the site of the attack, the locking mechanism will be forced open to allow access to the interior of the safe. Such "pound" jobs leave indented tool marks at the point of attack. If a small hole can be made in the outer cladding of the safe, it may be enlarged by ripping the cladding. Tool marks will be found at the point where the hole was started in the cladding and on the edges of the rip where the cladding was pulled away with pliers.

Electric drills can also be used to attack safes. A high-torque drill may be used to drill through the locking bars in the safe door. A jig or metal frame will be attached to the front plate of the safe door to position the drill properly. The safebreaker usually draws layout lines on the front plate to ensure that the jig is attached in the right place. These layout lines are important evidence and should be carefully photographed. A “drill” job leaves drill marks, both those made in the locking mechanism as well as those made in attaching the jig to the front of the safe. A core drill may also be used to drill a large hole in the side of the safe through which the safe contents can be removed. A jig is attached to the side of the safe to guide the core drill.

Most of the methods used to attack safes release safe insulation, which can be transferred to the perpetrator’s clothing, footwear, or tools. Safe insulation may contain Portland cement, vermiculite, gypsum, diatomaceous earth, or sawdust. Microscopic examinations may associate the trace evidence removed from a suspect’s clothes, shoes, or tools with the insulation in the safe. For such examinations to have value, the investigator must ensure that no cross-contamination between the safe insulation and the evidence taken from the suspect can occur. The investigator must be sure to collect a representative sample of the safe insulation for comparison.

Once tool marks have been identified at the scene of a crime they should be documented in the usual manner with notes, sketches, and photographs. The photographs should show the locations of the tool marks; however, even macrophotography will rarely show sufficient detail to allow the photographs to be used for laboratory comparisons. Photographs are often useful to the laboratory examiner as clues to how the crime scene marks were made. Once the documentation of the marks is completed, the tool mark evidence should be collected for subsequent laboratory examination. If the object bearing the tool mark can be transported, it should be collected and sent to the forensic science laboratory. The operative rule is that the thing itself is the best evidence, but if the object cannot be transported then a cast of the tool mark should be made. The ideal casting medium for tool marks reproduces the microscopic detail of the tool mark and is dimensionally stable, easy to use at crime scenes, and inexpensive. A variety of casting materials have been used to make casts of tool marks: negative moulage, low-melting metal alloys (e.g., Wood’s metal), and silicone rubber. The material that most closely meets the criteria of an ideal casting material is silicone rubber. It faithfully replicates the microscopic detail of a tool mark. It is dimensionally stable if is stored at room temperature and is relatively inexpensive. Silicone rubber casting material is sold as a partially polymerized base with which a catalyst must be mixed to complete the polymerization. The base material is filled with gray or red pigment particles. Silicone rubber casting material is available in two different viscosities; one has the consistency of thick cream, the other the consistency of putty. The thicker material is especially useful for casting tool marks on vertical surfaces. After the catalyst has been kneaded into the mass of base material, the mixture can simply be pressed into the tool mark.

### *14.7.3 Laboratory Examinations of Tool Marks*

In the forensic science laboratory, the tool mark examiner carefully examines the questioned tool mark along with any tools that have been submitted for examination. If the tool mark examiner concludes that the tool mark could have been made by a submitted tool, he or she will use the tool to prepare test tool marks for microscopic comparison. The making of such marks is the most time-consuming part of tool mark examination. For microscopic comparisons of the crime scene tool marks and the test marks to be successful, the test tool marks must be made using the same tool surface as that used to make the crime scene mark; moreover, the test tool mark must be made in the same way (particularly using the same **angle of attack**). The test tool marks are made using a malleable and ductile material such as lead, tin, or aluminum. These materials accurately reproduce the individual characteristics of the tool surface but are soft enough that they will not damage the tool surface.

The tool mark examiner makes microscopic comparisons of the test tool mark and the questioned tool mark in order to match markings made by individual characteristics of the tool. Individual characteristics of tools result from manufacturing processes, from wear, and from damage due to misuse. For example, the cutting edges of bolt cutters and wire cutters are usually hand-ground on a grinding wheel. This process results in each cutting edge having a unique pattern of striations. This pattern of striations will in turn produce a unique pattern of markings in a tool mark. Many modern manufacturing techniques, however, can produce tools that when new do not possess sufficient individual characteristics to permit the tool marks they make to be distinguished from one another. Occasionally, what appear to be individual characteristics on a tool are found to be class characteristics. For example, a screwdriver used in a series of break-ins was found to have a pattern of striations on the side of the blade and ripple marks on the face of the blade. These features matched marks left at the crime scenes; however, the forensic tool mark examiner discovered that screwdrivers of the same brand and size purchased at local hardware stores exhibited the same features. The striation pattern on the side of the blade and the ripple marks were produced by the die used to stamp out the blades of the screwdrivers. This case emphasizes the need for tool mark examiners to be familiar with the various techniques in the manufacture of tools. Confronted by tool marks made by an unfamiliar tool, the tool mark examiner may have to contact the tool manufacturer for information regarding production methods and even acquire examples of the different stages of tool manufacture. Figures 14.8 and 14.9 show microscopic comparisons of sliding tool marks and cutting tool marks, respectively.

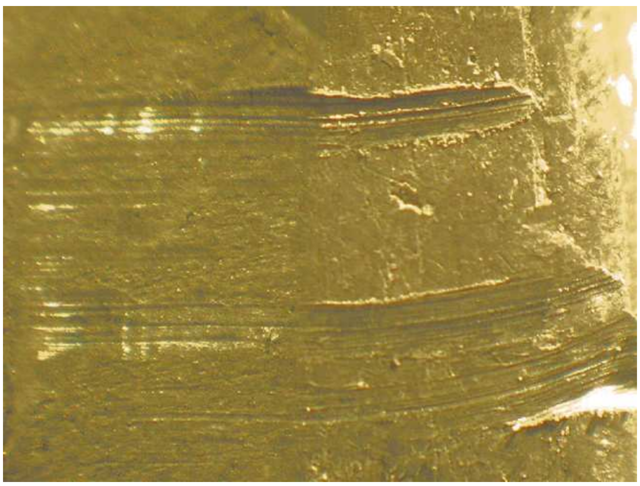

***Figure 14.8*** Microscopic comparison of sliding tool marks made with the same screwdriver.

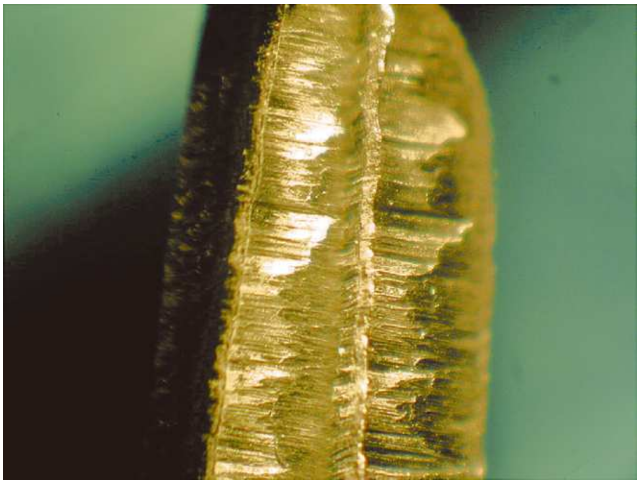

***Figure 14.9*** Microscopic comparison of cutting tool mark made with the same pair of shears.

As is the case with firearms examinations, tool mark examiners can reach one of three conclusions:

- *Positive identification*—The class characteristics (as far as they can be determined) are consistent and individual characteristics match. This means that the likelihood that a tool other than the tool submitted for examination made the tool mark is so remote that it must be regarded as a practical impossibility.
- *Negative identification*—The tool mark was not made by the submitted tool. This means that the class characteristics did not match. In this instance, no microscopic comparison will have been undertaken.
- *Inconclusive*—This means that the class characteristics match but that sufficient individual characteristics to declare a match could not be found. The tool mark examiner does not render a negative identification in this instance because the individual characteristics of the tool may have been altered by further use between the time it left the marks at the crime scene and the time it was collected as evidence by investigators.

### 14.7.4 Tool Marks on Manufactured Items

Tool marks on manufactured items may also be useful in an investigation. In the case of the kidnapping and murder of Charles Lindbergh's son, the planing marks on pieces of lumber used to fabricate the ladder used by the kidnapper led the investigation to the lumber mill in North Carolina where the boards had been cut; the lumber yard where the kidnapper bought the lumber was also identified. Unfortunately, the lumber yard did not keep records of cash transactions, so the identification of the kidnapper had to wait until he spent some of the ransom money. The following examples of tool marks made during manufacturing have proven to be forensically useful:

- Hammer marks on the heads of nails and brads
- Extrusion marks on pipe
- Machining marks on metal shavings

- Extrusion marks (and manufacturing defects) in plastic film, plastic cling wrap, and plastic bags
- Ream marks on sheets of flat glass
- Punch defect marks on illicitly manufactured drug tablets
- Extrusion marks on plastic sheeting
- Tool marks stamped into illicit drug tablets

## 14.8 Challenges to Firearm and Tool Mark Examinations

In the wake of the 1993 *Daubert* decision (Chapter 2) and the extended struggle over the admissibility of DNA evidence, many pattern evidence disciplines such as fingerprint identification and firearm and tool mark examinations have come under increased scrutiny by the courts. Critics of firearm and tool mark examinations have claimed that these examinations are wholly subjective. Firearm and tool mark examinations are partially objective and partially subjective. The microscopic examinations carried out by examiners are objective; the examiners' interpretations of those examinations in terms of whether a particular firearm or tool made the marks examined microscopically do have a subjective component. However, courts have held that subjectivity does not render tests unscientific and inadmissible. Critics of firearm and tool mark examinations have also argued that markings on bullets and cartridges and in tool marks lack sufficient individuality for the examiner to assert that a questioned bullet or cartridge was fired in a particular firearm or that a particular tool made the questioned tool mark. They have also objected to firearms examiners testifying that their examinations absolutely identify the firearm or tool that made the evidentiary marks that have been microscopically examined. Some courts have agreed that the conclusions of firearm and tool mark examiners should be limited to reasonable scientific certainty, rather than absolute certainty. Both the Association of Firearm and Tool Mark Examiners (AFTE, http://www.afte.org/) and the Scientific Working Group for Firearms and Tool marks (SWGGUN, http://www.swggun.org) have adopted interpretive guidelines that permit examiners only to state that the likelihood that another firearm or tool made the marks is so remote as to be considered a practical impossibility.

## Chapter Summary

In this chapter, we have seen how the act of discharging a firearm creates marks on surfaces such as bullets and cartridge cases. The markings include indentations and striations, which are features also seen in tool marks. These patterns can often be linked to a specific weapon or a specific tool. As was the case with fingerprints, a national database of firearms patterns exists (NIBN) but this is not the case for tool marks, which are so variable that, to date, such a database is not practical or feasible. In the next chapter, we will examine yet another type of pattern evidence—treads from shoes and tires; not surprisingly, databases are used extensively.

## 14.9 Review Material: Key Concepts and Questions

### 14.9.1 Key Terms and Concepts

Angle of attack
Assault rifle
Automatic weapons
Ball powder
Blowback
Bolt action
Bolt-face signatures
Breechblock
Broaching
Bullet wipe
Caliber
Cannelures
Cartridge
Centerfire cartridges
Choke
Compression tool marks
Contusion ring
Cut rifling
Cutting tool marks
Deterrents
Double-base smokelesspowder
Ejectors
Electrochemical etching
Extractors
Extruded powder
Firing pin impressions
Flash suppressants
Forcing cone
Frangible bullets
Full metal jacket bullets
Gas piston
Gauge
Gray ring
Griess test
Grooves
Gunshot residue
Hammer
Hammer forging
Headstamp
Helixometer
Hook cutting
Interior ballistics
Lands
Lever action
Maiti test
Marginal abrasion
Muzzle velocity
National Integrated Ballistic Information Network (NIBIN)
Nitrocellulose
Nitroglycerin
Nitroguanidine
Opacifiers
Primer
Pump action
Recoil
Revolver
Rifling
Rimfire cartridge
Scrape cutter
Semiautomatic weapons
Semi-jacketed bullets
Single-base smokeless powder
Skid marks
Sliding tool marks
Slippage
Smokeless powders
Sodium rhodizonate test
Soft-point bullets
Stabilizers
Stellate defect
Stippling
Striations
Swaging
Transitional ballistics
Trigger pull
Triple-base smokeless powder
Ultrasonic cavitation
Wads
Wadcutter

### 14.9.2 Review Questions

1. What general rifling characteristics of a firearm can be determined from a fired bullet?
2. In what ways can the caliber of a firearm be determined from a fired bullet?

3. What class characteristics of a firearm can be determined from an expended cartridge?
4. What markings on fired bullets are compared microscopically?
5. What markings on fired cartridges are compared microscopically?
6. What conclusions can a firearms examiner reach as result of a microscopic comparison of bullets or cartridges?
7. How is the range of fire estimated from a powder pattern?
8. How can the range of fire be estimated from a shotgun pellet pattern?
9. What are the three types of tool marks?
10. How should tool marks be processed at the scene of a crime?
11. What conclusions can a firearms examiner reach as result of a microscopic comparison of tool marks?
12. The energetic material in single-base smokeless powder is ________; the energetic materials in double-base smokeless powders are ________ and ________.
13. In a rifled gun barrel the raised areas are called ________, and the recessed areas are called ________.
14. Cut rifling methods are ________, ________, and ________.
15. Barrels with polygonal rifling are made by ________.
16. The two types of metallic cartridge priming systems are ________ and ________.
17. Markings made on the bases of cartridges by breech blocks are also called ________.
18. Three commonly used chemical methods for the visualization of powder patterns produced by ammunition having lead-based primers are ________, ________, and ________.
19. ________ reagent is used for visualization of powder patterns fired with ammunition containing lead-free primers.
20. An irregular, blown-out entrance wound in the skull is termed a ________ defect.
21. The ring of bullet lubricant, gunpowder combustion products, and metal from the bullet surface surrounding a gunshot wound is called ________.
22. ________, ________, and ________ have been used to make casts of tool marks.

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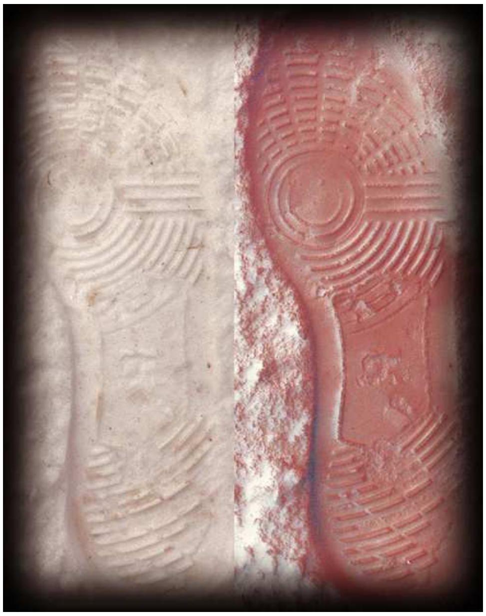
# 15
# Tread Impressions

## Chapter Overview

Fingers, guns, and tools leave pattern evidence; so do treaded items such as tires and shoes. Tires and shoes are mass-produced items, so at first it might seem that the best forensic scientists could do with a tire or shoe impression is link it back to the type of tire or a brand of shoe. However, often much more can be done with this type of evidence. Suppose you and a friend both purchase a pair of shoes from the same store on the same day. These shoes came off the assembly line one right after the other. Initially, the treads will probably be nearly identical. You wear these shoes every day and use them to play basketball on outdoor concrete surfaces. Your friend wears the shoes once in awhile and mainly indoors. Over time, the tread patterns will become worn, and these wear characteristics can be critical in differentiating your shoes from your friend's shoes. In this chapter, we will see how wear characteristics, as well as other principals, are used by forensic scientists to study tread pattern evidence.

# Chapter 15
# Tread Impressions*

*William J. Bodziak*

## Chapter Outline



## 15.1 Forensic Footwear Evidence

### *15.1.1 Introduction*

As persons walk about, their shoes track over a large variety of surfaces, constantly acquiring dust, dirt, residue, grease, oils, blood, and moisture. The shoes then deposit these acquired materials back onto other surfaces they subsequently track over. As a result, they leave a variety of both patent (visible) and latent (invisible) **two-dimensional impressions**. On softer surfaces, such as sand, soil, or snow, they often will cause permanent deformations of that surface in the form of **three-dimensional impressions**. The direct physical contact between the shoe and the substrate results in a transfer of class and individual characteristics from the shoe to the impressions it leaves. The forensic footwear examiner can examine these class and individual characteristics to determine if a specific item of suspect footwear made the questioned

* This chapter is based on Chapter 19, "Forensic Footware Evidence," and Chapter 20, "Forensic Tire Tread and Tire Track Evidence," both by William J. Bodziak, as published in the third edition of this text.

**SIDEBAR 15.1. CAREER PREPARATION AND EXPECTATIONS**

The preparation for careers in pattern evidence, including the analysis of tire impressions, is common across the various disciplines. Typically, entry-level positions require a college degree in a natural science followed by extensive training and apprenticeship with an experienced examiner. Examiners usually work in a laboratory setting but may occasionally be called upon to assist in obtaining impressions from crime scenes.

crime scene impression, or if that item of footwear can be eliminated. This process begins with detection and recovery of the footwear evidence from the scene of the crime, enhancing that evidence if appropriate, producing known impressions of the shoes being examined, and finally comparing the crime scene impressions with the footwear. The final result may require the footwear examiner to produce this evidence and provide his or her opinion in a court proceeding. Footwear impressions are routinely used to prove a suspect was present at the crime scene. This type of evidence is very valuable and most frequently used in homicides, assaults, robberies, rapes, burglaries, and similar crimes where the proof of an individual's presence is, in itself, incriminating. (For a discussion of career preparation for this field, see Sidebar 15.1.)

## *15.1.2 Forms of Footwear Impressions*

### *15.1.2.1 Three-Dimensional Impressions*

Three-dimensional impressions are those that remain after a shoe has permanently deformed a surface. This type of impression is typically found on exterior surfaces, such as sand, soil, or snow (see Case Study 15.1). Some of these impressions are very shallow while others may be deep. Depending on the composition of the substrate, the amount of moisture, and the presence of contaminants such as sticks, stones, and other debris, the resultant quality of the impression can range from those having great detail to those having little or no value. For instance, an impression in a clay-based soil will normally retain greater detail than an impression in a mixture of coarse sand and small rocks. Likewise, an impression in fresh snow will normally retain greater detail than an impression in wet or old refrozen snow. Three-dimensional impressions that retain sufficient detail can be identified with a specific item of footwear.

### *15.1.2.2 Two-Dimensional Impressions*

Two-dimensional impressions are those made on non-giving surfaces, such as tile, linoleum, or wood flooring, and also include those made on paper, plastics, doors, carpet, clothing, broken glass, countertops, etc. Any surface that can be stepped on or kicked by an item of footwear is capable of retaining a footwear impression. These impressions vary considerably because of the many combinations of dusts, dirt, soil residues, grime, oily materials, or blood acquired on the sole of the shoe, making the methods of recovering and enhancing those impressions more numerous and complex. Some impressions are highly visible, and others are latent. Shoes may track across a surface that contains dust or residue only to track later across a cleaner surface, depositing those traces of materials in the form of an impression.

**CASE STUDY 15.1: SNOW PRINTS**

During a snowstorm in a large city in the northeast, a convenience store owner was robbed and murdered in a manner similar to that of several prior robbery homicides. The assailant quickly entered the store, pointed the gun at the victim's head, and shot him. The assailant then jumped over the counter and emptied the cash register. As the assailant left the store, responding police pursued him on foot. The long chase continued through the blizzard, through buildings and alleys and over flat-topped roofs. Eventually the suspect was captured. He did not have the murder weapon in his possession. Cleverly, the police backtracked the perpetrator's shoe prints in the snow to an alley where he apparently had hidden momentarily beneath a small covered area. In this covered area they found the gun. Next to the gun were several shoe prints of the same design. All of the shoe prints were photographed and submitted to the laboratory for examination with the suspect's shoes. Examination of the shoe prints resulted in an identification of the shoe prints with the shoes the suspect was wearing when apprehended. This evidence was important because it linked the gun used in the homicide with the suspect. Testimony was given at the trial for this crime and the suspect was found guilty. The gun was subsequently identified with over a dozen other similar robberies and homicides in the same city. The suspect subsequently entered pleas to the other crimes.

Shoes that are wet or muddy or that have tracked through blood or other opaque materials can leave a variety of impressions on most surfaces. Even shoes that are relatively clean and dry can leave their impressions on paper or other surfaces such as glass or countertops that may be coated with polish, wax, grease, film, or grime. In each of these cases, the amount and type of material deposited by the shoe and how that material contrasts with the receiving surface determine how visible the impression is. It is interesting to note that often the less visible impressions actually retain greater detail than impressions that result from heavier deposits of residue, dust, or blood. Regardless of whether the impressions are full or partial, or heavy or light, the examination results depend on the detail retained in the impression.

### *15.1.3 Information and Use of Footwear Impression Evidence*

Footwear impressions located at a crime scene can provide a variety of information that assists in the investigation of a crime. Some of these applications are described below.

- *Identification of footwear*—Based on the agreement of both class and individual characteristics, a suspect's shoe may be positively identified as the exact shoe that left one or more impressions at the scene of the crime, thus proving the suspect's presence at the crime scene.
- *Elimination of footwear*—Based on confirmable differences of class characteristics, shoes may also be eliminated as the cause of an impression at the crime scene. Elimination of a suspect's footwear may be useful in accounting for all footwear impressions at the scene, and in some cases may constitute exculpatory evidence. Random individual characteristics on a shoe can change with wear as old ones are worn away and new ones are acquired. Not all individual characteristics reproduce all of the time in every crime scene

impression, and it is normal to find individual characteristics on a shoe that have not been retained in the impressions it leaves. For that reason, changes in a shoe or the absence of random individual characteristics are normally not used to eliminate a shoe.

- *Participation in the crime*—Footwear impressions found at the crime scene and identified with the shoes of persons who had no legal authority to be there are highly significant. For instance, footwear impressions left on objects such as broken glass inside the point of break-in, on paper items that were removed from a burglarized safe, on items that may have been knocked to the ground during an assault, or in the blood of the victim not only contribute significantly toward proof of a suspect's presence at the scene but also in evaluating his or her participation in the crime.
- *Location of impressions*—Impressions at the point of entry and exit and at other significant locations within the crime scene may provide a link or relationship to the location of other impressions or additional physical evidence.
- *Rebuttal or confirmation of suspects' alibis*—Suspects often admit their presence at a crime scene. The exact location and diligent documentation of shoe impressions may help to prove that the suspects are lying or being truthful about where they have or have not walked.
- *Determination of shoe brand*—The brand name and description of the footwear that left the crime scene impression can often be determined through footwear databases or by other means. In the United States, the Federal Bureau of Investigation (FBI) maintains a footwear database that includes thousands of shoe designs. At no charge to law enforcement agencies, the FBI will search crime scene impressions in an attempt to identify the manufacturer or brand of the footwear. This information may contribute toward the identification of the suspect or may be otherwise useful in the investigation.
- *Linking scenes of crime*—Databases in some laboratories can store the footwear impressions recovered from various crime scenes, often linking different crime scenes to one another. This is a particularly useful tool in investigations of repetitive crimes such as burglaries.
- *Determination of shoe size*—In many cases, if the manufacturer of the footwear is known, an accurate determination of the size of the shoe that made a full or partial footwear impression is possible. In other cases, the dimensions of full or nearly full impressions can allow for a general estimate of the shoe size.
- *Number of perpetrators*—The location of more than one suspect shoe design at the scene of the crime may provide important information about the number of persons that committed or were present during that crime. Likewise, the absence of more than one set of footwear impressions, under certain circumstances, may indicate that only one individual committed the crime.
- *Association with other evidence*—Backtracking footwear impressions from the point of entry, or tracking impressions exiting the scene, can assist in locating discarded weapons or other evidence and in associating the footwear impressions with tire impressions or other physical evidence.
- *Gait characteristics*—**Gait analysis** is used primarily for medical evaluation of persons with walking problems. The measurements of a person's stride, step length, and step width change as he or she walks more slowly or quickly, and as he or she walks over different surfaces. These variables also exist when known standards of a suspect's gait are obtained. Because of these variations, gait characteristics cannot be reliably used as a means of personal identification.

- *Tracking*—Tracking involves following the path of an individual by observing evidence that person has created as he or she passes over various surfaces. That evidence—referred to by trackers as "sign"—includes shoe prints, bare footprints, crushed debris or displaced rocks, and sticks or leaves that may have been stepped on. It is most commonly used for tracking illegal aliens and searching for missing children, but in some instances it has been used to track criminals from the scene of the crime. Most trackers in the United States originate from agencies such as the U.S. Border Patrol, where they routinely gain training and experience in tracking methods.

### *15.1.4 Location and Recovery of Footwear Impressions*

It is critical that the proper techniques and materials be used to locate, document, and recover footwear evidence from crime scenes. Unfortunately, some investigators still overlook this evidence, failing to look for it aggressively at the crime scene or failing to recover it properly. Success in locating footwear impressions and then recovering the maximum detail from each impression has a direct impact on the usefulness of this evidence and the results of any subsequent forensic examination. An interesting example is provided in Sidebar 15.2. Impressions that shoes leave may be full, but in most cases they are partial in that they do not represent the entire surface of the shoe's outer sole. Some partial impressions represent only a small percentage of the shoe sole that created it. Regardless, and even in the case of small partial impressions, all impressions can potentially contain sufficient detail for a meaningful examination result. It is not possible simply to look at a crime scene impression and determine its value. That impression's value will not be known until it is fully recovered, enhanced, examined, and compared with shoes. Therefore, all questioned footwear impressions should always be recovered from a crime scene.

**SIDEBAR 15.2. CURRENT EVENTS: COUNTER PRINTS**

In a West Coast city, four persons pulled up in front of a bank in a van. One of the individuals remained in the van. The other three entered the bank to commit the robbery. Once inside the bank, all three jumped onto the bank counter, brandishing their guns and demanding that the bank employees give them the bank money. They exited the bank not only with money but also with the explosive dye pack that was among the stolen money. The dye pack exploded seconds after they entered the van. The van came to a quick stop, and all four bank robbers quickly exited and fled on foot. Two responding police officers gave successful pursuit to two of the suspects. Back at the crime scene, investigators recovered numerous shoe impressions on the bank counter. These were enhanced with black fingerprint powder and lifted with white adhesive lifters. The impressions were searched through the FBI's footwear database. The impressions were all made by the same brand of athletic footwear, although each was a differently designed style of that brand name. Later, these impressions were compared with the shoes of the two apprehended suspects. One suspect wore a size 5 shoe and the other suspect wore a size 13 shoe. Both the left and right shoes of each suspect were identified with several of the impressions on the top of the bank counter. One suspect's clothing also contained the red dye from the exploded dye pack. Testimony was provided in the bank robbery trial and was instrumental in the jury verdicts of guilty.

Most impressions are on floor or other walked-upon surfaces, and if the scene is not properly controlled the shoes or equipment of other individuals can track over this evidence. To prevent this, the scene should be secured as soon as possible. This should include both the interior and exterior perimeters, because this evidence can be both inside and outside of the scene.

Some impressions are obvious and can be seen immediately upon entering the scene. For instance, bloody shoe prints on a light-colored surface next to a homicide victim are hard to overlook. Locating most footwear impressions, however, requires a more deliberate and aggressive effort. Making a slow visual search, followed by darkening the room and searching for impressions with a high-intensity oblique light source, often reveals many impressions that could not otherwise be easily seen. More aggressive techniques, such as searching for impressions with an electrostatic lifting device (ESD, described in detail in Chapter 17), may also be appropriate in certain areas, depending on the conditions. In addition, any items that have potentially been stepped on, such as pieces of paper on the floor, broken glass, or other surfaces that may have been walked over or kicked, should be closely examined. In most cases, paper items that are stepped on do not reflect visible footwear impressions, but they almost always contain highly detailed latent dust impressions that can be recovered electrostatically. Likewise, broken glass that falls inside of the point of forced entry is often stepped on and normally retains good to excellent impression detail, yet these footwear impressions can be seen only with proper lighting. Exterior surfaces, including the areas near any forced point of entry or any logical exit path, should also be thoroughly searched.

Notes should provide information about the location of all impressions as well as a brief description of each. These notes should be prepared in a way so they, along with the general crime scene photographs, can be used to document and reconstruct the scene and the relevance of the evidence. To document footwear impressions, numbered identifiers, such as those depicted in Figure 15.1, should be placed alongside each impression or other items of evidence. Whenever possible, general crime scene photographs should be taken with the numbered or alpha markers in place. The investigator's notes and photographs should reflect these evidence assignments to the respective impressions in any subsequent lifts, casts, or examination photography. In this way, a cast #3 can be directly linked to both general crime scene and


***Figure 15.1*** A general crime scene photograph, taken from medium range, to document the position of shoe prints and other evidence.


***Figure 15.2*** A general crime scene photograph, taken from close range, to document the evidence items such as this footwear impression next to identifier #3. This type of photograph is for documentation only and is not intended nor satisfactory for a comparison with a suspect's shoes.

examination-quality photographs of these impressions, as well as the notes regarding those impressions. Examples of this are depicted in Figures 15.1 and 15.2. Figure 15.1 is a medium-range photograph of a burglary crime scene at the exterior forced point of entry. It depicts three pieces of evidence—two shoe impressions (3 and 4) and a discarded pry bar (5)—and shows their location and relationship to the overall side of the residence and the point of entry at the door. Figure 15.2 is a close-range photograph depicting shoe impression 3. It is not intended for an examination, but simply to show more closely the position and orientation of that impression.

Any impressions at the scene that can be carefully recovered should be taken to the laboratory. This includes paper and broken glass, area rugs and flooring with bloody shoe prints, and similar types of evidence that can be safely removed. If the impression is on an item that cannot be removed from the scene, it should be recovered in a prescribed and proper manner as described below. All impressions, both partial and full, are of potential value and should be recovered.

Footwear impressions that cannot be removed and taken to the laboratory such as on concrete or asphalt, must first be photographed in a special manner to provide high-quality photographs for a forensic examination. This type of photography is known as **examination-quality photography**. Examination-quality photographs of impression evidence are taken strictly for a forensic examination with suspected footwear. The impression in the general crime scene photograph in Figure 15.2 was subsequently photographed in this way, as shown in Figure 15.3. A ruler, used as a scale, should be positioned alongside of the impression and should be used in every photograph. It is also important to place the ruler on the same plane (level) as the bottom of three-dimensional impressions. In this way, the ruler will provide a way to enlarge the photograph accurately to a natural size for examination. If the ruler is not used, or if it has not been placed on the same plane as the impression, it will significantly reduce the ability to use the photograph for a forensic examination. To hold the camera in the proper position and to maintain focus, the camera must be placed on a tripod. The camera and tripod should be positioned directly over the impression so that the impression and ruler fill the entire frame. The camera should be manually focused on the bottom of the impression and not on the ruler.

Certain three-dimensional impressions, such as those in white sand or snow, are very difficult to photograph with contrast. For impressions in snow, **Snow Print Wax™** or dark-colored aerosol paint can be carefully applied lightly at an oblique

*Figure 15.3* An examination-quality photograph of footwear impression #3, featured in Figures 15.1 and 15.2. This photograph was taken with a ruler placed along side of the impression and with the camera positioned on a tripod directly over the top of the impression. By using the scale of the ruler, this type of photograph can be enlarged to a natural size and then compared with a suspect's shoes.

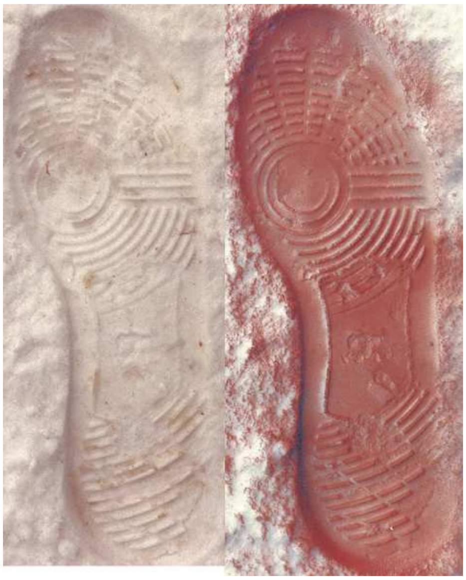


*Figure 15.4* Impressions in snow are difficult to photograph. On the left is an impression as it would appear in a normal examination quality photograph. The impression was then highlighted with a light spray of Snow Print Wax™ and rephotographed. The highlighted impression provides much better contrast and detail for examination. This is an excellent way to document impressions in snow.

angle to highlight the ridges or high spots of the impression, thus adding some contrast in the photographs. The left side of Figure 15.4 depicts an impression in snow. On the right is a photograph of the same impression after it was highlighted with the red-colored Snow Print Wax.

### *15.1.4.1 Two-Dimensional Impressions*

Once the impression has been photographed, two-dimensional impressions, in many cases, can be lifted. Lifting of two-dimensional impressions can improve the visibility and detail of the impression by transferring it to a surface that provides better contrast. It also enables the removal of the impression from the crime scene to the laboratory. There are many methods and materials for lifting. Electrostatic lifting is a method that utilizes a high-voltage power source to create a static electrical

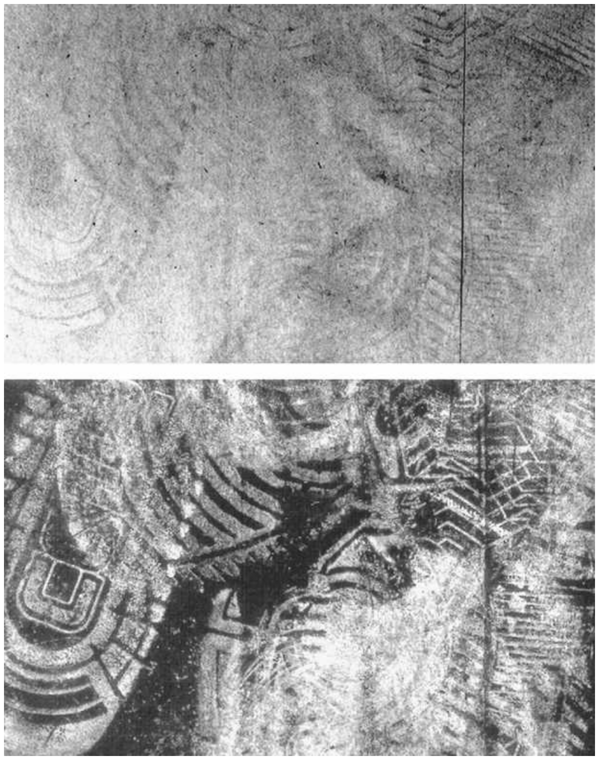


***Figure 15.5*** The top photograph is a high-contrast photograph of shoe impressions on a folder. The bottom is a photograph of the impression on the black lifting film after it had been electrostatically lifted. Electrostatic lifting not only increases contrast but also reveals dry origin latent shoe impressions on evidence and floor surfaces that may have been walked over.

charge that enables the transfer of a **dry origin impression** from the surface to a special black lifting film. A person walking across dirty or dusty surfaces who then steps on a cleaner surface, such as paper or a tile floor, will create dry origin impressions on those surfaces. These dry origin impressions do not have a tight bond with the substrate and can be electrostatically lifted. The method of electrostatic lifting is normally used first, particularly when it is not known if the impression was one of dry or **wet origin**. Should the electrostatic lift be unsuccessful, the evidence will not be harmed, and other lifting or enhancement methods can still be used. Figure 15.5 depicts the value of electrostatic lifting. At the top of Figure 15.5 is a paper folder containing dry origin dust impressions. On the bottom is the electrostatic lift of those impressions on the black lifting film. The increased contrast provided by the electrostatic lift allows for the visualization of much greater detail, and thus a more productive examination. Electrostatic lifts are fragile. They must be stored properly and must be photographed before they can be fully utilized in an examination.

If an impression will not lift with the electrostatic method, the impression either is a wet origin impression or is composed of other materials that have bonded to the surface. In some cases, fingerprint powder can be used to enhance impressions. If this is successful, the impression should be re-photographed first and then lifted with a gelatin or adhesive lifter or with **Mikrosil®** casting material. Unlike adhesive and gelatin lifters, Mikrosil will conform to textured or uneven surfaces. It also will often lift the entire powdered impression, making it a very good choice for impressions that have been developed with fingerprint powder but are still very faint. Whatever lifting material is used, it should be of a color that provides good contrast with the color of the fingerprint powder. Transparent lifters are not recommended

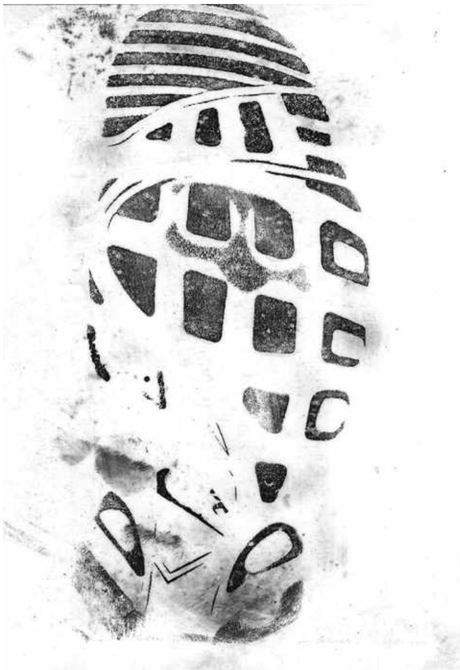


***Figure 15.6*** A white adhesive lift is one method of lifting a shoe impression that has been enhanced with black fingerprint powder on a nonporous surface.

because they do not provide sufficient contrast with either an original impression or powdered impression. A white adhesive lift of a black-powdered impression, such as that pictured in Figure 15.6, is an example of a lift that provides excellent contrast. If the powder were gray or silver, a black gelatin lift would provide the best contrast.

### *15.1.4.2 Three-Dimensional Impressions*

All three-dimensional impressions should be cast with **dental stone**. Dental stone, like plaster, is a gypsum product, but dental stones, unlike softer plasters, set much harder, have a higher compressive strength, retain greater detail, and provide a quick and easy way to recover three-dimensional impressions. Dental stones having a compressive strength of around 8000 to 9000 pounds per square inch are sufficiently hard to be cleaned without loss of detail. Although dental stone can be mixed in a bucket, the more popular and common use for casting footwear impressions involves placing a 2-pound portion into several zip-lock bags to have on hand when needed at a crime scene. The proper amount of water for the 2-pound portion can then be added to the bag at the crime scene and combined within the bag. The exact amount of water will depend on the powder-to-water ratio for each particular dental stone product and can be found on the dental stone box or accompanying information sheet. It is extremely important to mix the water and powder in the zip-lock bag for a minimum of 3 minutes to ensure that the powder has had ample time to absorb the water. The casting material should not be poured directly into the impression but carefully poured next to the impression in a way so it will naturally flow into the impression. Once certain areas of the impression are covered with the dental stone, the bag can be moved to facilitate an even distribution of casting material over the entire impression. The dental stone material will harden in approximately 20 to 30 minutes. It will take another 24 to 48 hours for all of the water inside the cast to evaporate, after which the cast will become fully hardened. Only then is it safe to


***Figure 15.7*** On the left is a cast of impression #3 in Figure 15.3 that recovers additional detail and provides a more accurate piece of evidence with regard to size. A cast should always be made of all three-dimensional impressions. Beside the cast is the suspect's shoe to which it will be compared.

clean the cast by immersing it in water and using a soft brush to remove any sand or soil. Figure 15.7 depicts a dental stone cast of the impression featured in Figure 15.3 and a picture of the shoe suspected of making the impression. Impressions in snow can also be cast with special methods and materials.

### *15.1.5 Enhancement Methods*

Many crime scene impressions are indistinct, have poor contrast with the surfaces they are on, or are altogether invisible. There are several ways to develop and enhance these impressions, thus providing more detail for later examination (see Case Study 15.2). Some of these methods reveal latent footwear impressions that would otherwise go undetected. In other instances, visible, yet faint or indistinct, footwear impressions are improved visually after enhancement. Specialized lighting and photographic techniques are nondestructive and, therefore, a good first method of enhancement. The use of oblique-light, high-contrast, ultraviolet, infrared, and other special photographic methods, as well as equipment, such as alternative light sources, can provide increased contrast and visibility of many impressions. Impressions that are photographed or scanned can be digitally enhanced with computer software such as Adobe® Photoshop®. The software can be used to increase contrast and brightness and can improve visualization of the impressions in a number of other ways. Digital methods of enhancement are often used to further enhance impressions that have already been enhanced with photographic, physical, or chemical methods.

Physical methods include various methods of lifting impressions, powdering impressions with fingerprint powder, and recovering indented footwear impressions on paper items. As we saw with fingerprint evidence there are also chemical methods for enhancing impressions. There are many commonly used methods for chemically treating both bloody footwear impressions and non-bloody impressions. Reagents used to enhance blood impressions include leuco crystal violet, diaminobenzidine, and luminol. Some reagents commonly used to enhance residue impressions include,

**CASE STUDY 15.2: IMPRESSIONS IN CARPET**

On an island in the Caribbean, a young man reported that two unknown assailants attacked him and his father at 2:00 a.m. in his father's office. He advised that he escaped after receiving only minor cuts but feared for his father's life. The police met him at his father's office and found that the father had been stabbed to death. A pool of blood was present where the father had been stabbed near the front door. Bloody drag marks indicated that the father's body had been dragged across the light-colored carpet, down a hallway, and into a back room. The investigators initially thought they could see bloody shoe prints, but were not really sure. They suspected the son, whose story was uncertain and constantly changing and whose wounds were very minor and more than likely self-inflicted. He was also unable to provide any real description of the alleged two assailants that he said had attacked both him and his father. The investigators seized the shoes of the son as well as his father's shoes. The son's shoes were dress shoes with a leather heel and sole. The heel was characterized by its shape and size and by the cut corner from the inner side of each heel. The sole also had a row of stitching around its perimeter. The carpeting from the entire office was seized and examined approximately two months later. There was no visible evidence of any footwear impressions on the light-colored carpeting, although the pools of blood and drag marks were still visible. The carpeting was chemically treated with luminol to enhance any faint traces of blood. This enhancement resulted in the detection of 41 footwear impressions. All of these corresponded with either the left or right shoe that the son was wearing. The son's alibi had never included his return to the office after he claimed he fled, so it would not account for any possibility of his shoes acquiring the blood and subsequently depositing all of these impressions. All of the impressions were either within or alongside of the drag marks, linking them to the activity involving the father's body. No other footwear impressions were detected. According to the son, two assailants had killed his father; yet, the absence of other footwear impressions in blood in the office did not support the presence of other assailants and, thus, further challenged the son's alibi. If two other assailants had killed the father and dragged his body though the office, either their shoes or their feet would have left bloody impressions. These did not exist. Faced with this evidence, the son entered a plea of guilty.

but are not limited to, physical developer (PD) and potassium thiocyanate. The left side of Figure 15.8 depicts a piece of clothing bearing a faint footwear impression in blood. The right side depicts the same impression after enhancement with leuco crystal violet. Figure 15.9 depicts faint footwear impressions in blood on a magazine, and Figure 15.10 shows the same impression after enhancement with diaminobenzidine.

### *15.1.6 Examination of Footwear Evidence*

Footwear impressions recovered from the crime scene area are intended to be those impressions made by the shoes of the perpetrator or perpetrators; however, impressions left by other persons at the crime scene, or additional impressions of unknown origin, may also be among those recovered. For elimination purposes, it is often necessary to document the designs of the shoes of victims, or of police officers, medical

***Figure 15.8*** On the left, a faint bloody footwear impression on a piece of fabric provides very little contrast but is an important piece of evidence. This impression was enhanced chemically with leuco crystal violet (LCV), as shown on the right, which provided excellent enhancement. LCV is used extensively for the enhancement of bloody impressions both at crime scenes and in the laboratory.

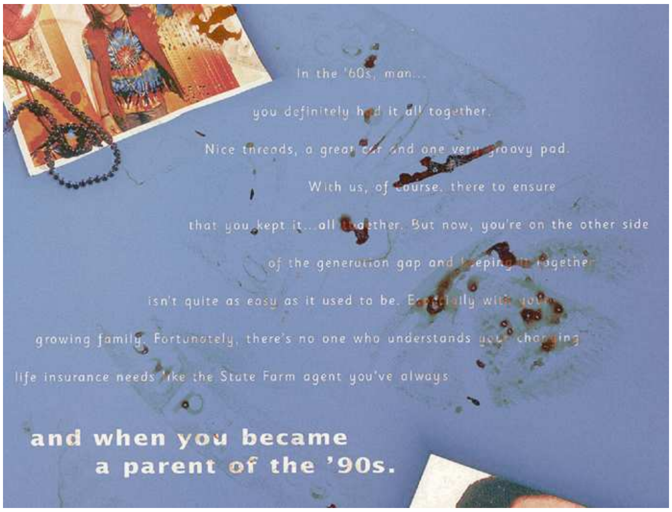



***Figure 15.9*** A bloody impression on a magazine is hardly recognizable as a shoe print.

personnel, or other persons who were also present at the scene and whose shoes may have left impressions. These impressions are referred to as *knowns* or *exemplars* (also discussed in Chapter 17).

Shoes seized from a suspect within minutes to an hour after the crime might appropriately include only the shoes that the individual is wearing at the time of arrest; however, most persons own more than one pair of shoes and often possess more than one pair of shoes of their favorite design. For this reason, shoes obtained from a suspect many hours or days after the crime should sensibly include all footwear that a suspect owns and not just the footwear the suspect happens to be wearing at the time of questioning or arrest to avoid missing that evidence. The actual shoes are needed for a forensic examination in order to make known test impressions and to allow for the proper evaluation of class and individual characteristics. Photographs of the shoes or test impressions of the shoes made by a third party, in lieu of seizing the actual shoes, are not acceptable for a full and thorough examination.

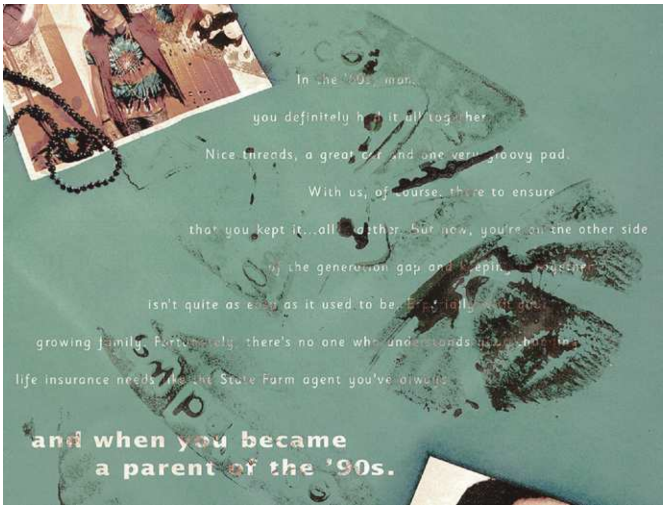



***Figure 15.10*** The same blood impression depicted in Figure 15.9, after it has been chemically enhanced with diaminobenzidine. The impression now reveals excellent detail for comparison, including portions of the name of the shoe brand.

**Elimination footwear** includes footwear worn by medical personnel, police officers, or other innocent persons, who, in addition to the suspect, could possibly have left the recovered impressions. Due to the thousands of footwear designs that exist, crime scene impressions left by the perpetrator will rarely, if ever, be the same design as those worn by other individuals at the crime scene. Because the shoe design worn by the perpetrator is rarely known when the crime scene is processed, it is important to attempt to account for all impressions recovered from the crime scene. By documenting the shoes of others who walked through the crime scene area, their shoe designs can be eliminated as those of the perpetrator. Consideration should be given to obtaining a digital photograph or a test impression of the footwear of those other individuals so their shoes can be accounted for. The shoes of such individuals could then be obtained later in the rare event that their shoes were of a similar design as the suspect's shoes. During the examination made between a crime scene impression and suspect's shoes, the examiner makes **known impressions** of the suspect's footwear to assist in the evaluation and comparison of this evidence. Figure 15.11 depicts a known test impression of a shoe. Methods of making known impressions utilize inks, fingerprint powders, special paper, casting materials, and other products that reproduce the characteristics of the shoes being examined. The purpose of making known impressions is not to attempt to recreate the exact circumstances that were present at the scene of the crime, but to produce highly detailed replications of the class and individual characteristics of the shoes. These known impressions are then used to assist the examiner in comparing the shoe directly with the crime scene impressions.

### *15.1.6.1 Examination Process and Conclusions*

When shoe soles come into contact with a receiving surface, such as a floor, kicked door, or piece of paper, that contact results in the direct physical transfer of the class and individual characteristics of that footwear. These characteristics can be compared with the respective characteristics of the footwear alleged to have made them. Footwear examinations involve comparisons of both full and partial crime scene impressions with known shoes. The comparison process utilizes side-by-side

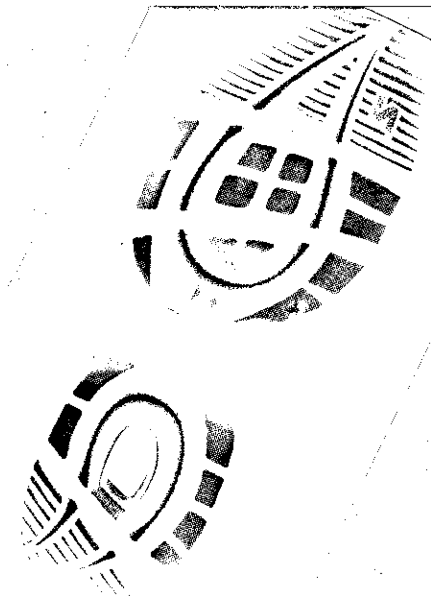


***Figure 15.11*** Several known shoe impressions of the suspect shoe, like the one depicted here, are used to assist in the comparison of the questioned impression with the suspect shoe.

and superimposition methods, assisted by low magnification, specialized lighting, and the known impression exemplars. The examination of the class characteristics of design, physical size, and general wear and the presence of any individual characteristics form the basis for the examiner's resulting opinion.

The most obvious class characteristic of any impression is its design or pattern. Thus, it is normally the first area to be compared. There are many thousands of shoe designs, with new ones arriving on the market as older designs are discontinued. Depending on how the shoe has been made, the specific features of that design can even vary slightly among different shoes of that general design. Any design features that are clearly evident in the questioned impression must correspond sufficiently with the suspect shoe in order for the examiner to conclude that the shoe design corresponds. During the examination, if the general design is clearly different, then the suspect shoe can easily be eliminated. If the design of the impression corresponds with the respective area of the suspect shoe, then the examination process continues. Because there are so many design choices the suspect could be wearing, a conclusion that the suspect shoe design corresponds with the crime scene impression design does have some significance.

The physical size and shape features pertain to the actual dimensional features of the impression and are not a reference to the manufacturer's shoe size. Each shoe design manufactured comes in many different sizes. The soles of these different-sized shoes have different dimensions or proportions of their design throughout the size range. Consequently, the physical size and shape feature of soles are of comparative value during examination of the crime scene impressions. During the examination, the evaluation of the shoe design and of the physical size and shape features of that design are evaluated together. When a crime scene impression corresponds in both design and physical size of that design with the suspect's shoe, the association has a high evidentiary value. This is so because there is an extremely large number of possible design and size combinations, and any particular design–size combination represents an extremely small fraction of 1% of the total overall shoe population.

When shoes are worn, their sole designs become altered by the abrasive forces created as they make repetitive contact with the ground. Some areas of the sole receive more wear than other areas. As the wear progresses, noticeable areas of greater wear develop. Over time, as long as the shoe continues to be worn, the degree of wear will increase and the areas of wear will enlarge. The degree of correspondence in wear between a crime scene impression and a perpetrator's shoe recovered soon after the crime is highly significant. If the suspect's shoes are not recovered until some time later, the extent to which wear can be factored into the examination may be affected. As a routine matter, the examiner should know the dates on which the crime scene impression was made and the suspect's shoes were seized. During the examination, the wear will be examined to assess the position of wear and the degree of wear. The position of wear is the area or areas on the sole that reflect visible wear. Not all persons wear their shoes the same and the wear areas on the shoes of one person may differ from the wear areas of others. The degree of wear is the extent to which those areas are worn. Some shoes may be virtually unworn, while the design may be completely worn away in certain areas of other shoes. As shoes continue to be worn, the degree of wear will increase. Correspondence of the position and degree of wear of shoes that are obtained shortly after the crime is very significant because it offers an additional means of eliminating other shoes of the same size and design that would not have the same general condition of wear. In some cases, shoes may be new or nearly new and exhibit no visible **wear characteristics**. In other cases, the detail retained in the questioned impression may not be sufficiently clear to enable an accurate assessment of the condition of wear of the shoe that made it. With these limitations, the relevance of wear may be minimized or incapable of accurate evaluation and comparison. Although general wear can provide a significant contribution to the overall basis and results of the examination, general wear features of footwear, even if matched precisely with the scene impression, are not a basis alone for the identification of the shoe with the impression. In some cases, it is possible to use wear to eliminate a shoe from having made an impression; however, this must be done with caution and is only possible when the questioned impression reflects the wear characteristics clearly.

Individual characteristics are characteristics that have been randomly added to or removed from a shoe sole after the shoes are worn. They most commonly include cuts, scratches, gouges, tears, and other physical damage that can occur to the surface of a shoe sole during its use, but they also include materials that may be randomly attached to the shoe sole, such as tar, gum, nails, tacks, and stones wedged between the tread design. Figure 15.12 shows an impression of an athletic shoe on the left side and the respective portion of the actual shoe on the right side. The shoe contains many highly individual cuts and tears. A few of these are indicated with arrows. The randomness of the manner in which each of these features is acquired means that none is likely to have the same shape or size nor be in the same position and orientation on any other shoe, much less another shoe of the same design and physical size. It is likely that you would not be able to find even one similar-looking individual characteristic in the same position on another shoe of the same design. These randomly acquired features provide a high degree of individuality to an item of footwear and serve to distinguish the soles of one item of footwear from all others.

When a crime scene impression and a shoe sole share sufficient individual characteristics, a positive identification can be made. A positive identification is a conclusion that a particular shoe, and no other shoe, made the crime scene impression. Although positive identifications are normally a result of finding two, three, or many more individual identifying characteristics on a shoe sole, a single characteristic may be all that is needed to identify a shoe with a crime scene impression, provided

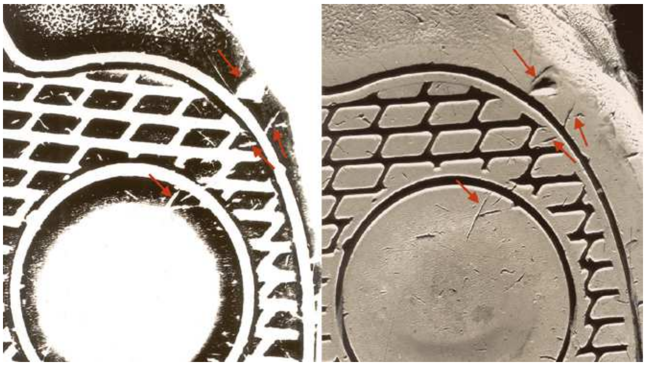


*Figure 15.12* A portion of a shoe on the right, with arrows pointing to a few of the many individual identifying characteristics. These individual cuts or tears in the shoe sole are acquired during its use and make this shoe different from all others. The same characteristics can be seen in the test impression made by that shoe, pictured on the left. Characteristics like these enable concluding that a particular shoe made a particular impression.

that the single characteristic was sufficiently clear and reflected sufficient features in common with the scene impression. The number of random individual characteristics is not nearly as important as the specific features, the clarity of those characteristics, and the ability to associate the characteristic's features in the shoe with those in the crime scene impression.

## 15.2 Tire Impression Evidence

### 15.2.1 Introduction

Tire impression evidence shares many characteristics with footwear impression evidence. Tire impressions can be two- or three-dimensional. Photography of the evidence plays a critical role in its analysis and casts can be made at crime scenes. **Tire tread impressions** reflect the tread design and dimensional features of the individual tires on a vehicle. A tire tread impression is depicted in Figure 15.13. These tread impressions can be compared directly with the tread design and dimension of the tires from

*Figure 15.13* This examination-quality photograph of a tire impression depicts the tire tread design. The photograph, taken with a scale placed on the same level as the bottom of the impression, can be enlarged to natural size and compared with the suspect tire and tire impression exemplars from the suspect tire.

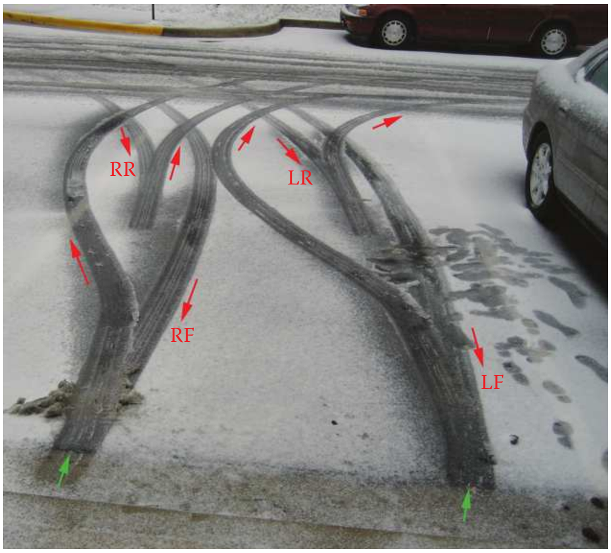



***Figure 15.14*** A general crime scene photograph of tire tracks in the snow is an important phase of the recovery of tire impressions. The relative position of the impressions, their directionality, and other track features and dimensions must be documented at the scene.

a suspect vehicle. If the impression produced sufficient detail, this comparison can result in highly significant conclusions, including positive identifications. With less detail, the comparison can still provide good evidence that the suspect vehicle possessed the same tread design, dimension, and possibly other corresponding features.

**Tire tracks** are the relative dimensions between two or more tires of a vehicle. Tire tracks reflect general information about the vehicle that left the impressions. By measuring the dimensions of tire tracks at the crime scene, it may be possible to determine or approximate the track width, wheelbase, or turning diameter of the vehicle that created those impressions. Tire tracks can be sometimes be used to profile the type or size of vehicle used and provide other information that can help to include or exclude a suspect vehicle. Some tire tracks are shown in Figure 15.14.

## *15.2.2 Types and Characteristics of Automobile Tires*

### *15.2.2.1 Original Equipment Tires, Replacement Tires, and Tire Construction*

There are thousands of tire designs in the world, and most of them come in numerous sizes. Tires that are sold as equipment on new vehicles are known in the automotive industry as **original equipment manufacturer (OEM) tires**; however, most refer to these tires simply as **OE tires**. OE tires of the same size and brand are used on thousands of the same make and model vehicle. Replacement tires are those purchased to replace worn or damaged tires. They are often not the same design as the OE equipment. The choice of a particular replacement tire design is made by the vehicle's owner and is influenced by factors such as availability, price, and personal preference. Multiple vehicles with three OE tires of one design that have one replacement tire of a different design occur when a single tire must be replaced and the OE brand and style are either unavailable or not chosen. Instances of multiple vehicles possessing two replacement tires, each of a different design, is a far more rare occurrence, but a significant one because of the large number of combinations possible. A vehicle with three or even four replacement tires, each of a different design, constitutes a highly unique situation.

Most passenger tires today are of **radial ply** construction, although **bias-belted** truck tires are still made. Bias belted tires have plies running beneath the tread at an angle (bias) across the tire but with the addition of belts beneath the tread surface. In radial tires, the plies run straight across the tire, from bead to bead. Because of the direction of the radial plies, radial tires are more efficient at reducing the amount of squirm (contraction and expansion) of the surface of the tire during use. Tires are built from a variety of components, including the liner, sidewall rubber, plies, beads, belts, and tread rubber. These components are made of various compounds of unvulcanized rubber, steel, and fabric. They are assembled on a rotating and collapsible drum. The tread rubber, a thick layer of rubber without any design on it, is applied last. The tire at this point, known as a **green tire**, contains no tread design or sidewall information. The green tire is then placed in the tire mold where the tire components are vulcanized and the tread and sidewall designs are molded into the finished tire. Although we will focus on car tires, other tires can be of forensic interest as described in Case Study 15.3.

#### *15.2.2.2 Tread Nomenclature and Sidewall Information*

Figure 15.15 illustrates some general tire tread nomenclature. Tire treads are composed of many tread blocks. Some are arranged in ribs around the circumference of the tire, and others are formed to create patterns. These tread blocks are separated by grooves. Some of the grooves may also run circumferentially around the tire, but many grooves run across the tire design. Grooves that run across a tread are called **slots** or **transverse grooves**. If you look closely into the grooves of a tire, you will see some raised areas known as **tread wear indicators** or **wear bars.** Most passenger tire tread blocks also contain very small grooves that are called **sipes**.

In addition to the visual information of the tread design, which can be associated with a specific brand name and manufacturer, much information is also molded into the sidewalls of the tire. Each tire has two sidewalls. The outer sidewall or **label side** is the side that a whitewall or raised white lettering is on. This is the side intended to face outward on the car. The inner sidewall, known as the **serial side** of the tire, is the side that is normally not visible. Some of the sidewall information is of importance to the investigator or examiner and should always be noted when examining a tire. The tire brand and style name, such as Michelin XM+S 244, and the size of the tire, such as P 195 75/R15, are normally on both sides of the tire and should be noted first. The serial side traditionally contained the Department of Transportation (DOT) number and the mold numbers; however, tires are now required to have the DOT information on both sidewalls. The **DOT number** begins with the letters "DOT" and contains important information (Figure 15.16). The two digits (letters or letter and number) that follow the DOT prefix, such as AP, are symbols for the manufacturer and plant code. The plant code indicates the exact location where the tire was made. The Tire Guides, Inc., publication *Who Makes It and Where* lists plant codes and shows that a tire with a plant code of AP was manufactured at the Uniroyal Goodrich Tire Manufacture in Ardmore, Oklahoma. The final three or four digits of the DOT number, which are numbers, are also important since they provide the week and year during which the specific tire was manufactured. In Figure 15.16, the numbers "3704" indicate that the tire was made during the 37th week (37) of 2004 (04). Tires made after January 1, 2000, have four numbers in this position, whereas tires made in 1999 or earlier have three numbers; for example, a tire made during the 49th week of 1999 or 1989 has the numbers 499.

## CASE STUDY 15.3: CAR AND BIKE TRACKS

In a rural residential neighborhood, a teenaged girl rode her bicycle home from a friend's house after school. During her trip home, she rode down a dirt road in an isolated area. Along this road she was intentionally struck and forced off the road by a car and knocked off her bike. The assailant placed the stunned girl on the passenger floorboard of his small lime-green vehicle. As he drove away through the adjacent community in which the victim lived, he leaned over to hold her down. Later, some persons in that community recalled seeing a lime-green car with a man leaning over toward the passenger side. They independently provided sketches of the assailant. Many weeks later, the remains of the homicide victim were found tied to a small tree.

At the abduction scene, tire tracks were present where the perpetrator veered off the main path of the dirt road over to a softer shoulder next to the area where the car struck the victim and knocked her off her bicycle. The shoulder was a mixture of soil and rocks, but the detail of a full tire impression was present for several feet. Investigators photographically recovered the impression.

In time, the suspect was identified when someone recognized the artist sketches produced from the witnesses that lived in the victim's neighborhood. His car contained four Yokahama tires and a spare. Some of the tires, including the spare tire in the trunk and the right front tire, reflected some very unusual wear characteristics due to mechanical problems with his vehicle. The right side of the vehicle also contained some rubber scrape marks similar in height to the rubber handle grips of the victim's bicycle. Comparison of the tires with the tire tread impression from the scene resulted in correspondence of the tire design, dimension, and noise treatment. The tire design and dimension had been used in very limited numbers of vehicles imported several years prior. Normally, most of those tires would be worn out, but the suspect's vehicle had not been used for an extended period of that time due to his incarceration in a mental facility. His vehicle, therefore, was still equipped with the original tires, which were no longer commonly found. The position and degree of wear also corresponded. Even more significant was the fact that the wear extended around the edge of the shoulder of the tire, beyond where it would normally occur. This unusual wear was found to be a result of a severe mechanical problem with the front right wheel assembly of the suspect's car. The examination results were critical to proving the case at trial.

**Retread tires** have slightly different DOT numbers, such as DOTR YPY 1201. An example of a retread number is shown in Figure 15.17. The retread DOT number should begin with the letters "DOTR" or "R," but in reality this prefix may not always be present. The original DOT number will still appear on the sidewall of the tire, as required in order to know the date of the original tire carcass. DOTR numbers beginning in the year 2000 consist of three letters and four numbers as in the Figure 15.17 example. The three letters "YPY" identify the location and facility where the tire was retread. The Tire Guides, Inc., publication *Who Retreads Tires* lists, by their three-letter code, thousands of facilities that retread tires. The final four numbers identify the week and year the tire was retread. Tires retread in 1999 or earlier have a three-number designation here.

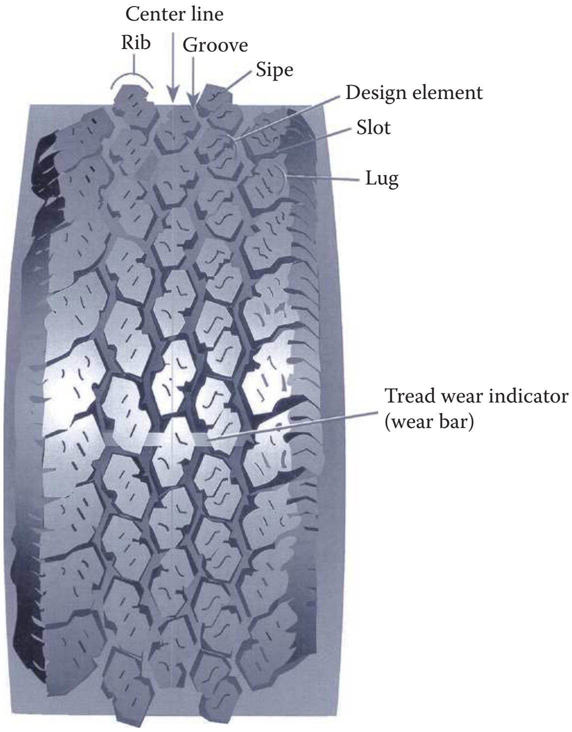



***Figure 15.15*** Some basic terminology of a tire tread.


***Figure 15.16*** The Department of Transportation (DOT) number includes information that tells where and when that tire was manufactured.

| **DOTR** | **YPY** | **1201** |
|---|---|---|
| ↓ | ↓ | ↓ |
| "DOTR or "R" indicates a retread tire | Goodyear retread Frederickton, NB Canada | Date of manufacture 12th week of 2001 |

***Figure 15.17*** The Department of Transportation requires a different number arrangement on retread tires. It may or may not begin with the letters "DOT" or "DOTR." The letters and numbers indicate the date and the specific location where that tire was manufactured.

Numerous tire-size designations have been used over the years. A commonly used size designation for passenger tires is the P metric system. A P metric size designation, such as P 195/65 R 15, can be broken down as follows:

P = passenger tire
195 = approximate section width in millimeters
65 = aspect ratio
R = radial tire
15 = rim diameter in inches

Included in the tire size is the aspect ratio, which reflects the ratio of the height of a tire to its width. Tires with low aspect ratios, such as 45 or 55, look flatter and proportionally wider. A tire with a higher aspect ratio, such as 70 or 75, looks taller and narrower.

### *15.2.2.3 Noise Treatment*

As a tire turns under load, the tire tread blocks vibrate and produce harmonics or noise. If the tread blocks of a tire were all one size and pitch, the noise would be greater than is desirable. To reduce this type of noise emitted by the tires, the tire industry has created tire designs that change the size (pitch) of the tread blocks around the tire, thus creating a variety of pitches. This and other engineered factors that help reduce the noise a tire generates are referred to in the industry as **noise treatment**.

Years ago, noise treatment of a tire was simpler and might only have involved the creation of three sizes of tread blocks: small (S), medium (M), and large (L). Their sequence around the circumference of the tire was simply S, M, L, S, M. L, S, M, L, and so forth. Later, the sequences became more random, such as S, L, M, S, S, L, M, M, L, M, L, S, continuing with a similarly random order of the three sizes around the full circumference of the tire. Figure 15.18 illustrates a basic example of noise treatment using a mixture of S, M, and L tread block sizes. The difference in size is visually obvious. You can look at virtually any passenger or light truck tire made today and see how the tread block sizes vary around the circumference of a tire. The modern tire is developed with sophisticated computers that are capable of creating complex tire designs and noise treatments. The mixed arrangement and sequence of varied tread block sizes is far more complex, to the degree that a sizeable segment of a tire impression will only represent one nonrepeating segment of this tire. An example of a more complex design is represented in Figure 15.19. This diagram depicts the varied arrangement of four sizes of tread blocks around the circumference of the tire.

Forensic tire examiners must understand the concept of noise treatment and include it in their evaluation of the dimensional aspects of a tire impression as compared to a tire. The noise treatment permits the examiner to find the exact locations on a suspected tire or tires of the same design and general tread dimension that potentially made the crime scene impression, improving the quality and accuracy of

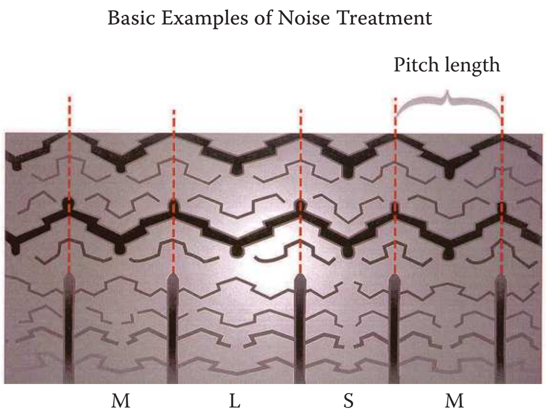



***Figure 15.18*** The tread blocks around most tires are a mixed arrangement of various pitch sizes. This helps reduce tire noise at higher speeds. The industry's method of doing this is known as noise treatment. In this example, the tire has a mixture of tread blocks that vary in their pitch length and are small (S), medium (M), or large (L).

the full-tread dimensional analysis. Noise treatment is usually different on opposite sides of the tire, which can be helpful in certain cases where the direction of the vehicle is at issue. Off-the-road tires and retread designs often do not have noise treatment.

#### *15.2.2.4 Tread Wear Indicators (Wear Bars)*

A tread wear indicator (Figure 15.15), also known as a wear bar, is a raised rubber bar that is 2/32 inch above the base of the tire grooves. The Department of Transportation requires that all tires over 12 inches in diameter contain a minimum of six tread wear indicators around the circumference of a tire. As the tire tread wears down to the height of 2/32 inch, the wear bars become very noticeable. The purpose is to indicate to the car's owner that the tire should be replaced. Tread wear indicators will only record in a two-dimensional impression after the tire tread has worn down to the remaining 2/32-inch depth. Tread wear indicators can be retained in three-dimensional impressions, regardless of the condition of the tire, as long as the impression is sufficiently deep to record them.

Tread wear indicators are added to the tire design in different locations relative to the complex and varied noise treatment. Because of this, when tread wear indicators are present in a tire impression, the position of that tread wear indicator, combined with the position of the noise treatment, can offer valuable information during any subsequent examination of tires. To illustrate the importance of this, Figure 15.19 shows the positions where the six tread wear indicators occur in the tread design. The four orange sections of Figure 15.19 represent four examples of portions of the tire that might leave an impression or that might be recovered at the crime scene. For illustrative purposes, these four areas contain the same sequence of noise treatment. One of these areas does not contain any tread wear indicator. Three of the sections do contain a tread wear indicator; however, each of those three tread wear indicators is in a different portion of the noise treatment. Thus, tread wear indicators can be used in combination with the noise treatment to locate or eliminate areas of a tire that may have made the scene impression.

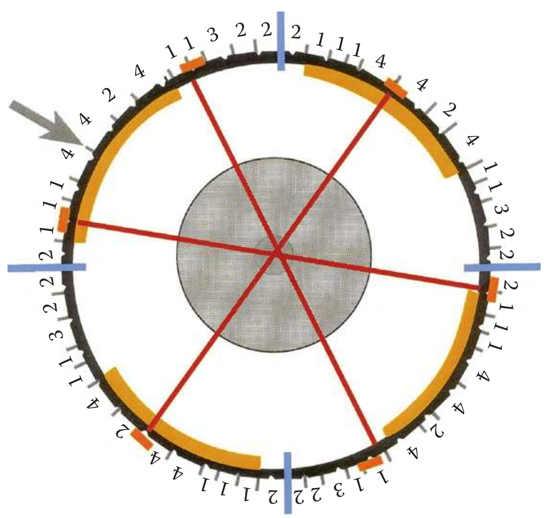


***Figure 15.19*** A diagram that shows a more complex arrangement of four tread block pitch sizes. In this example, the arrangement repeats four times (in between the blue lines). The red lines indicate the position of the tread wear indicators. Note that even though the noise treatment repeats four times, in each case the tread wear indicators intersect that noise treatment at a different location. This is extremely important to understand during examination.

#### 15.2.2.5 *Retread Tires*

In the United States, few passenger car tires are replaced with retread tires; instead, most retread tires are produced for fleet vehicles such as medium- and short-haul trucks and school buses, for which the cost difference between new tires and retread tires is substantial. Two processes are used in the production of retread tires: the **mold cure process** and the **precure process**. The mold cure process utilizes strips of raw rubber that are applied to the used tire carcass. The tire carcass is then placed into a mold where the tread design is molded into the new rubber. The precure process utilizes tread rubber already containing the tread design with a system of bonding that attaches it to the original carcass. Some retread tires reflect valuable individual characteristics that are a product of the retread process and offer the examiner additional information during the examination. The many designs and lower quantities of retread tires may attach additional significance to the association of a retread tire impression with a particular vehicle.

### 15.2.3 *Tire Reference Material and Databases*

Thousands of tire designs are made for a variety of vehicles and in a variety of sizes. Since the 1960s, the annually published *Tread Design Guide* by Tire Guides, Inc., has provided photographs of most tires' designs. The publication *Who Makes It and Where* lists where tires are manufactured. Both guides are published yearly in hardcover form. Also available is a more comprehensive version of both guides on a CD-ROM (www.tireguides.com) that includes over 18,000 tire designs. Investigators can use either one of these reference sources to link a tread design from a crime scene to a particular design and brand of tire.

### 15.2.4 *Tire Track Evidence*

**Tire track width**, **wheelbase**, **turning diameter**, and the relative positions of multiple turning tracks are collectively referred to as tire track evidence. Many crime scenes offer little or no tire track information due to limited quantity or quality of that evidence. For instance, at one particular scene, only one tire may leave its impression, and this impression may be relatively straight. At other scenes, a full set of four tire tracks both entering and exiting the crime scene may be retained by the soil. In any case, documenting and measuring the relation of tire tracks to one another can yield valuable information about the vehicle that made the tracks.

Track width (**stance**) is the measurement made from the center of one wheel or impression to the opposite wheel or impression. Figure 15.20 depicts the measurement of track width relative to a vehicle's tires. In most cases, a vehicle's front and rear track widths are engineered to be slightly different. As a vehicle travels forward in a straight line, the rear tire tracks will track over the top of all or most of the tracks left by the front tires. The front wheel measurement is therefore not often clearly present at a crime scene for measurement. If the vehicle is in a turn and the front and rear tracks are separated, the front track width can be measured but will not be accurate. This is because as the vehicle enters a turn, the track width between the front wheels will become narrower and cease to be a reliable measurement. Regardless of traveling straight or in a turn, the rear track width will always record accurately so the most reliable crime scene track width will always be obtained from the rear tire tracks. Track measurement must be made

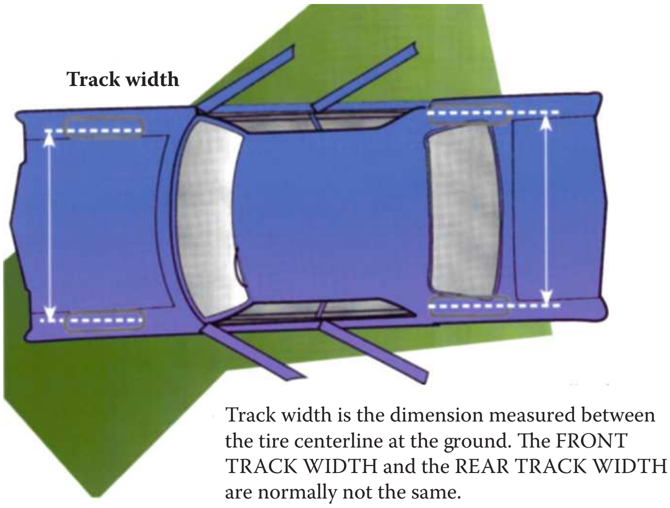



***Figure 15.20*** Track width is the distance between the center of the tire on one side to the center of the tire on the other side. This measurement should be carefully made at the crime scene and cannot be later determined from photographs.

perpendicular to the track. Figure 15.21 illustrates how to record a track width measurement. The industry standard is a center-to-center measurement, as shown in Figure 15.21, which is the best and most accurate measurement to make. In some instances, however, the left or right tire tracks may be partial or limited, so Figure 15.21 also shows other ways to make this measurement. With outside-to-outside measurement, the width of the tread must be subtracted from the measurement to result in a center-to-center measurement. With inside-to-inside measurement, the width of the tread must be added to the measurement to equal the center-to-center measurement.

The wheelbase of a vehicle is the measurement between the centers of the hubs of the front wheels to the centers of the hubs of the rear wheels. At a crime scene, different points needed to make this measurement are rarely present. Even under optimal conditions, sufficient detail rarely remains in both the front and rear tire tracks that are necessary for this measurement. In some instances, a vehicle parked

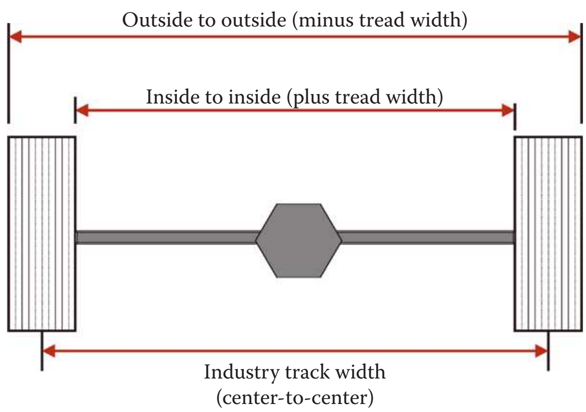



***Figure 15.21*** Although the industry measurement for track width is from center to center, it is possible to make this measurement in other ways, as illustrated here. The other measurements are a good way to verify the center-to-center measurement or, in some cases, may be the only method to use if the tire impressions are not complete.

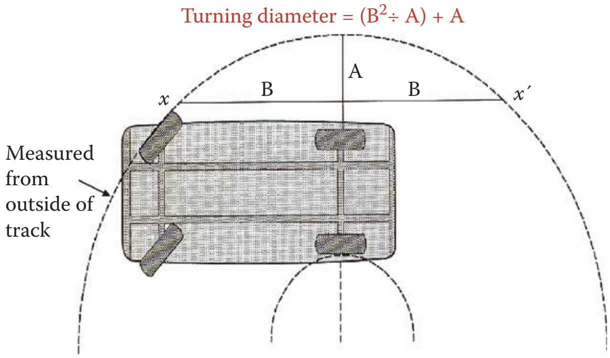



***Figure 15.22*** Every vehicle has a minimum turning diameter. Some vehicles can turn very sharply in small circles, whereas other vehicles make much wider turns. This diagram depicts how to measure and calculate the turning diameter if turning tire tracks are present at the crime scene.

in snow, or a vehicle parked briefly during a light rain, will leave four patches that mark the bottoms of the four tires. In other instances, tracks in snow or soil that involve turns and changes in direction may enable an accurate measurement.

The turning diameter of a vehicle is the diameter of the circle a vehicle makes when its steering wheel is fully turned. The measurement pertains to the tracks of the front wheels only, as they are the turning wheels. Some vehicles are capable of smaller turning diameters, while others are limited to a larger turning diameter. In general, smaller cars have a much smaller turning diameter than larger cars. The turning diameter and formula for calculating that diameter are illustrated in Figure 15.22. The measurements are made from two selective points, $x$ and $x'$, on the outer margin of the tire track of the outside front tire and the distance (A) between the outer margin and a point midway between $x$ and $x'$. The formula can then be used to calculate the diameter of the turn. Vehicles normally increase their amount of turn while entering a turn and decrease their amount of turn while leaving a turn. In addition, vehicles often turn at less than their minimum turning diameter. So any turning diameter measured at a crime scene does not necessarily represent a vehicle's minimum turning diameter and can only be used to eliminate any other vehicle that is not capable of turning at least that sharply. Whenever selecting the points of the turning tracks to measure, remember to select those portions that appear to represent the sharpest turn. It is always a good idea to make more than one measurement from different places in the turn to ensure that the sharpest point is included.

When a vehicle travels in a straight line, the rear tire tracks run almost directly over the tracks of the front tires. For that reason, there are normally only two tracks to measure in a straight-traveling vehicle—those of the rear tires. When a vehicle is turning, the front and rear tires track separately and the rear tires will track to the inside of the path of the front tires. This is shown in Figure 15.23. This important knowledge is useful in documenting the relative positions of tire impressions at a crime scene, particularly if the vehicle had different tires of more than one design or tires that were in different conditions of wear.

Too often, tire impressions are photographed, cast, or measured at a crime scene only for it to be discovered later that no one had documented where they came from. Scenes that contain various tread designs are often complicated and sometimes difficult to evaluate at the scene. It is wise to take your time, approach the area cautiously, and take general scene photographs from many angles. After this has been done, additional examination-quality photographs should be taken, followed by the casting of the tread impressions.

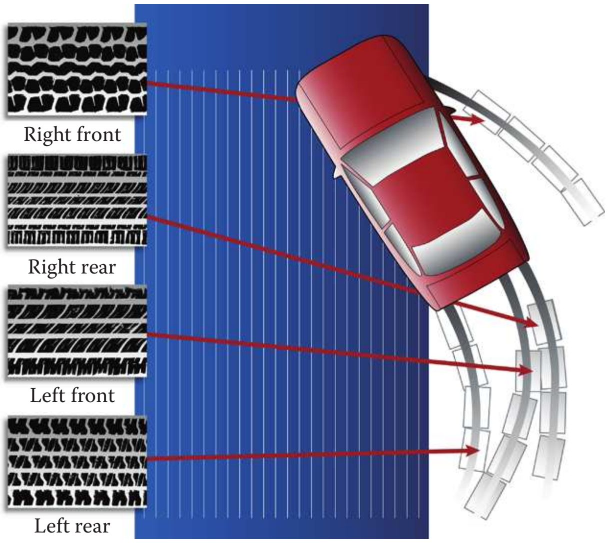



*Figure 15.23* Vehicles sometimes have more than one tire tread design, or the tires are in different stages of wear. This information must be accurately documented at the crime scene.

General crime scene photographs of the tire tracks and tire impressions, such as those in Figure 15.14, should be made from various angles to document all tire evidence. Diagrams and other written documentation to describe the number of tracks, their relationship to one another and the surrounding area, the track width, the direction of travel, and other pertinent information should supplement the photographs. Additional information, such as the relationship of the tire impressions to shoe impressions or other tire impressions crossing through the scene, should also be documented, both in writing and through photography.

Then, examination-quality photographs of the tire impressions, such as those in Figure 15.13, should be made. The examination-quality photographs are those taken for later detailed examination of the tire tread. These photographs are made in nearly the same manner as for the recovery of footwear impressions discussed previously. One difference lies in the occasional need to document a longer tire impression (over 12 inches in length) by making sequentially overlapping photographs. For instance, with longer impressions, several examination-quality photographs may have to be taken in a sequence that not only records each segment of the tire impression but also allows the overlapping segments to be spliced together later in order to reconstruct the longer impression for examination. One method that can be used to take these sequenced photographs is illustrated in Figure 15.24. These photographs depict three segments photographed in a sequence that can later be enlarged to natural size and pieced together to reconstruct the full tire impression. A long tape measure or yardstick can be placed alongside of the full length of the impression as a reference to help to splice together the series of overlapping photographs of the long impression later. A scale, such as a flat 12-inch ruler, should be placed alongside the length of each segment of the impression as it is photographed. It is very important that the ruler be placed on the same plane as the bottom of each segment of the impression. After the segment is photographed, the 12-inch ruler can be moved to the next segment being photographed. No ruler or scale should be placed within the impression or across the impression. The camera should be placed on a tripod and adjusted so that an approximately 14- to 16-inch segment of the impression is photographed each time. Only the center 12 inches will be used. After each

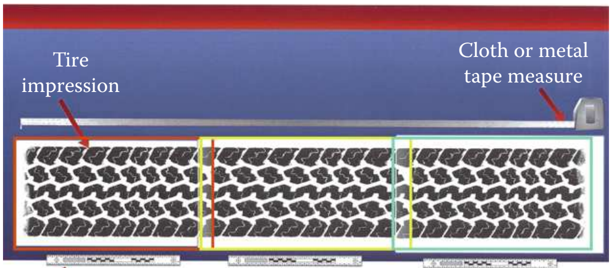



***Figure 15.24*** To photographically document long tire impressions, a series of overlapping photographs must be taken. This picture depicts how a 3-foot impression could be photographed with three overlapping photographs. The photographs, once enlarged to natural size, could then be spliced together to recreate the crime scene impression.

segment is photographed, the camera and tripod should be advanced approximately 12 inches along the length of the impression where the next photograph will be taken. The second photograph will overlap the first photograph, and the third photograph will overlap the second, and so forth. This process should be repeated until the full length of the impression is photographed. With this method, the sequential segments can each be enlarged to natural size and then can be assembled to recreate the full impression.

Casting a long tire impression is extremely important. A cast will provide an examiner with more information and will likely result in a far better examination result. Casting a long tire impression may present some challenges not associated with the casting of smaller footwear impressions. To allow the examination to utilize the noise treatment of a tire fully, it is essential to cast long sections of each tire impression being recovered. Although it may not be possible to cast the full length of every tire impression at a scene, any impression that is 4 feet in length or smaller should always be cast in its entirety. Making casts of larger impressions are less practical as they are very heavy and difficult to manage, and they require excessive amounts of casting materials. For instance, a tire impression that is 10 feet in length cannot be cast in one piece; however, at least one 3- to 4-foot section of the portion of that impression that appears to contain the best detail should be cast. In addition, a 3- to 4-foot section of the best-detailed portion of any other impressions at the scene should also be made. A 3-foot cast of an average tire impression will require approximately 15 to 25 pounds of dental stone depending on the tire tread width and the depth of the impression. This can be easily mixed in a bucket after adding the dental stone to the proper quantity of water. The mixture then can be poured carefully into the impression. After the cast has been poured and begins to harden, information about the impression, such as the impression number and the direction of travel if known, should be written on the back of the cast. Before the casts of the tire impressions are lifted, they should all be photographed in order to verify their relative position to one another and to the overall scene.

Figure 15.25 illustrates a cast of a tire impression. A transparent known impression of the suspect tire has been placed over it to show the correlation of the design and dimensional features. More often than not, a cast of a tire impression will provide the best physical evidence for later comparison with a tire. Casts produce a more accurately scaled representation of the impression than photographs. Casts also

***Figure 15.25*** This photograph illustrates a portion of a cast of a tire impression. A transparent inked tire exemplar, taken from a suspect vehicle tire, has been placed over the cast to illustrate how the design, dimension, and noise treatment of the tire correspond with the crime scene cast.

recover certain features that a photograph cannot recover, such as the three-dimensional aspects of the impression, its contours, and its uneven qualities and depth. These are very important when making a comparison with the tires. Some deeper impressions may even retain portions of the sidewall detail, so the dental stone should always fill the entire impression in order to recover that detail. Occasionally a crime scene will involve a vehicle equipped with a **dual tire assembly** (i.e., two tires mounted side by side). When this occurs, both tire impressions should be photographed and cast as a single unit because the relative position of one tire's noise treatment to the noise treatment of the other tire is of extreme importance.

### *15.2.5 Forensic Analysis of Tire Impression Evidence*

A tire tread examination involves the comparison of a tire impression recovered from the crime scene with tires taken from a known vehicle. Tires from known vehicles can be divided into two categories. First are the tires on a vehicle of a suspect that is believed to have left the impression at the crime scene. Second are those tires from other vehicles, known as **elimination vehicles**, which include emergency vehicles that may have inadvertently left tire impressions in the crime scene area. These are also referred to as *exemplars*.

Because there are so many different tire designs, the crime scene impressions will almost always be a different design than any tires from police, emergency, or other elimination vehicles. For this reason, it is normally not necessary to go to great extremes obtaining elimination prints or photographs of these vehicles. A digital photograph or small impression of the tires, combined with information identifying the tire brand, the vehicle it belongs to, and the position on the vehicle it came from, is all that is needed. Once documented, these elimination vehicles can always be accessed later should full test impressions of their tires be needed.

If the tire designs of the suspect vehicle are similar to the crime scene impressions, it is necessary to seize those tires for a full examination. When the tires are taken, the position of each tire (left front, right rear, etc.) and the side of the tire that is facing outward on the vehicle should be noted and should be marked directly on the tires before they are removed from the vehicle.

Full circumference test impressions of the tires are required to provide a comparable standard for comparison with a crime scene impression. These are normally made in a prescribed manner by the examiner with inks or powders on long pieces of solid-core chart board or on clear film taped over the chart board. The impressions may be taken with the tires mounted on the suspect vehicle, or alternately, on a vehicle that will accommodate that tire size. The tires should always be seized because the actual tires are required in order to perform a full examination.

Tires should not be removed from trucks or trailer rigs that have dual wheel assemblies because of the relationships between the tires mounted on the dual wheel. Demounting those tires would make them lose their noise treatment position relationship, which, in turn, would eliminate that important aspect of any dual tire impressions recovered from the crime scene. In order to preserve the position relationship, it is necessary to obtain test impressions directly from any suspect vehicle on which the dual tire assembly is mounted.

Tire impressions are the resulting transfer of the tread detail of a tire against the substrate. The impressions are a direct one-to-one transfer of their design, size, and other acquired features. These impressions can be three-dimensional impressions in soil, sand, or snow or can be two-dimensional impressions made after a tire tracks through dust, blood, or other materials. Their features can be physically compared with the tires from a suspected vehicle and also, if necessary, with the tires from emergency or police vehicles for the purpose of elimination. The examinations routinely allow for elimination of tires as well as positive identification of tires.

The forensic examination of a questioned crime scene tire tread impression begins with a visual comparison of that impression with the tread design of each known suspect or elimination tire. If the design is different, an elimination of that particular tire is made. Should the design be similar, the examination process continues and normally requires at least two staggered full circumference test impressions of each tire being examined. Figure 15.26 depicts a segment of a full circumference inked impression exemplar of a suspect tire that has been found to correspond in tread design and dimension and noise treatment with a cast impression. The known

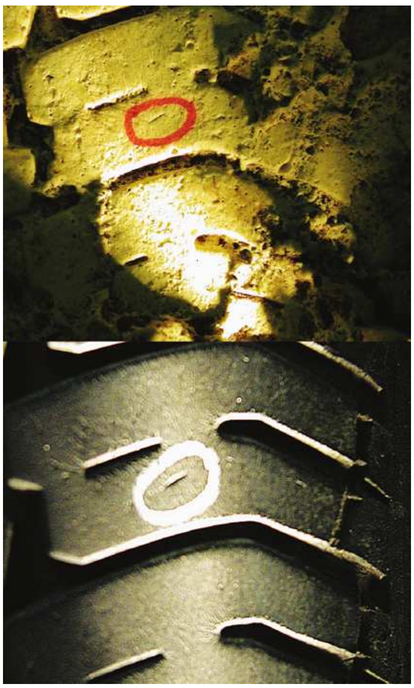


***Figure 15.26*** In some cases, a tire impression can be positively identified as having been made by a particular tire. The identification requires the presence of individual characteristics that are present in both the crime scene impression and the proper location on the tire. This photograph illustrates an individual characteristic that is visible in the cast above and in the respective area of the tire below.

impression of the tire is on clear material, allowing for a direct one-on-one superimposition of the known impression over the questioned cast impression. During this type of comparison, the inked impression is used as a tool to help compare the actual tire with the crime scene impression. The following areas are examined.

Tread designs contain a very specific and detailed arrangement of tread blocks, grooves, and sipes. Some tread designs appear similar to others, but to conclude that a design corresponds means that the design is the same and that all of the design portions visible in the questioned impression are also present in the known tire.

Tread dimension, or size, refers to the specific physical tire tread size, whereas noise treatment is the variance of the pitch (size) of the tread blocks as they are arranged around the circumference of the tire. Most tires come in several sizes. The tread dimension and noise treatment features in the questioned impression should correspond with the known tire. Note that the dimensional features that a tire leaves in some crime scene impressions, particularly those over uneven surfaces, may vary slightly from a known exemplar of that tire taken on a perfectly flat surface. Understanding the noise treatment sequence and other comparison factors enables the proper interpretation of such data during examination.

**Wear features** are crucial to the examination of tire impression evidence. As tire treads wear, the frictional forces cause erosion of the rubber and ultimately change the visible features of the tread blocks, sipes, and some grooves; for example, some sipes and even some lateral grooves will partially disappear as the tire tread is worn away. Many of these wear features may be noticeable in the questioned impression and can be compared with the appropriate sections of the known tire. Although not in itself a basis for identification, some tires contain highly significant wear features that are recorded in the impressions they leave. The wear features serve to reduce significantly the possible number of other tires of that same design and dimension that would be in the same general condition of wear and that could have potentially left the questioned tire impression.

**Random individual characteristics** include scratches, cuts, tears, and abrasions that have occurred to a tire in a random manner during its use. They also include the acquisition of stones, glass, nails, and other artifacts that have been either temporarily or permanently embedded themselves in the tread surface in a random manner. These characteristics, if present in both the questioned impression and the known tire, make that tire unique and allow for positive identification of that tire as having made the questioned impression. Figure 15.26 shows an individual characteristic in the cast crime scene impression and the corresponding individual characteristic on the tire. The characteristic is a small cut that has randomly occurred on the tire during its use. Its size, shape, and orientation, as well as its precise position on the tire, as confirmed by the corresponding noise treatment and other features, make it highly valuable for purposes of identifying this tire as having made this impression.

## Chapter Summary

This chapter concludes our discussion of traditional pattern evidence. From fingerprints to tire impressions, pattern evidence is treated virtually the same—features are used to classify impressions, and the details, be they minutiae or wear characteristics, are exploited to link a source to a questioned sample. Databases have become a critical tool for pattern evidence analysis and comparison, and each year these databases grow larger and more inclusive.

## 15.3 Review Material: Key Concepts and Questions

### 15.3.1 Key Terms and Concepts

Bias belted
Dental stone
DOT number
Dry origin impression
Dual tire assembly
Elimination footwear
Elimination vehicles
Examination-quality photography
Gait analysis
Green tire
Known impressions
Label side
Mikrosil®
Mold cure process
Noise treatment
Original equipment manufacturer (OEM) tires (OE tires)
Precure process
Radial ply
Random individual characteristics
Retread tires
Serial side
Sipes
Slots
Snow Print Wax™
Stance
Three-dimensional impressions
Tire track width
Tire tracks
Tire tread impressions
Transverse grooves
Tread wear indicators
Turning diameter
Two-dimensional impressions
Wear bars
Wear characteristics
Wear features
Wet origin impression
Wheelbase

### 15.3.2 Review Questions

1. How should a scale be properly used in photographing a shoe impression and why is it used?
2. What material is used to cast footwear impressions?
3. Name and briefly describe four methods of enhancing footwear impressions.
4. What areas are examined in a footwear impression comparison?
5. What is the purpose of making known impressions of shoes during an examination?
6. Name three materials that can be used to lift a shoe impression that has been treated and enhanced with fingerprint powder on a nonporous tile floor, and indicate which one will make the most complete lift.
7. Some footwear impressions are latent or hardly visible. Do these impressions contain sufficient detail for examination?
8. What information can a shoe print provide in an investigation? Name at least three.
9. State if a partial footwear impression can be examined and identified. Explain.
10. Are class characteristics or individual characteristics normally used to eliminate a shoe?
11. What four areas of the tread are involved in a forensic comparison?
12. What is "track width"? Explain how it is measured.
13. Differentiate between a "tire impression" and "tire track."
14. What does the term "OE" tires mean, and what are "replacement tires"?
15. What is the "DOT" number on a tire, and what are two important pieces of information that it contains?

16. What does the term "noise treatment" refer to?
17. What are "tread wear indicators," and how often must they appear around a tire?
18. What is the Tread Design Guide, and how might it assist in an investigation with tire tread evidence?
19. Should a cast be made of a three-dimensional tire impression, and if so, why?
20. Explain why it is important to document the positions of tire impressions at a crime scene, both photographically and otherwise.

## 15.4 References and Further Reading

### 15.4.1 Books

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### 15.4.2 Journal Articles

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Skerrett, J., C. Neumann, and I. Mateos-Garcia. "A Bayesian Approach for Interpreting Shoemark Evidence in Forensic Casework: Accounting for Wear Features." *Forensic Science International* 210, no. 1-3 (Jul 2011): 26–30.

# Section VI Summary

Pattern evidence represents one of the largest and oldest of the forensic disciplines. The fundamental tool used in all pattern evidence analyses is comparison, usually of a known sample to a questioned sample, such as a latent fingerprint recovered from a crime scene compared to a record in an IAFIS system. How these comparisons are made may differ, but fundamentally pattern evidence is about comparison. In the next section, we will begin with a discussion of questioned documents, a forensic discipline that has many elements in common with pattern evidence; for example, handwriting can be considered to be a form of pattern evidence. Questioned documents also share many characteristics of trace evidence, so this topic makes for a natural link between pattern and trace evidence.

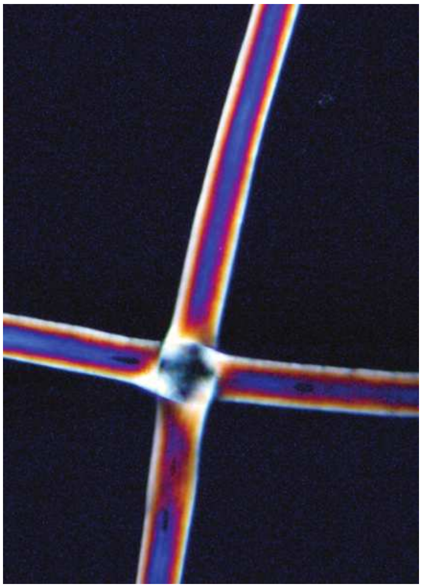
## Integrative Questions

1. What role does the examination of striations play across all types of pattern evidence?
2. Discuss the importance of proper collection and documentation of pattern evidence. How can poor collection practices impact the forensic analysis?
3. Obtain a copy of the 2009 National Academy Report on forensic science. What were some of the criticisms offered with regard to pattern evidence? How can these be addressed?
4. Could DNA evidence be considered to be a type of pattern analysis? What about arson evidence? How are these two examples similar to the pattern evidence types described in this section? How are they different?
5. If you were on a jury in which a potential murderer was identified by a fingerprint, how would you feel about this identification compared to an identification made through DNA? What are the similarities and the differences?
6. Discuss the following terms as they apply across all types of pattern evidence. How are they similar and how are they different depending on the discipline?

   Exemplar
   Elimination pattern
   Individualization
   Wear patterns
   Class characteristics
   Knowns
   Minutiae

# SECTION VII

# Cross-Cutting Forensic Disciplines



## Section Overview

We have seen forensic disciplines that rely on advanced instrumentation for analysis (drug analysis and toxicology, for example) and disciplines that rely on patterns and pattern matching (arson, fingerprints, firearms and toolmarks, and tread impressions). In this section, we will study forensic disciplines that integrate all of these practices to analyze a wide range of physical evidence types. In trace analysis, the microscope is the fundamental tool, be it a standard light microscope, a polarizing light microscope, or a microscope with an instrument integrated into it. Questioned document examiners utilize physical and chemical measurements as well as pattern matching in the context of handwriting analysis. Trace analysis and questioned documents are thus two of the best examples of integrative and cross-cutting forensic science as practiced today.

# 16
# Trace Evidence

## Chapter Overview

Trace evidence can literally be anything. As we discussed before, Locard's exchange principle tells us that every contact leaves a trace and that evidence such as hair, soil, glass shards, and so on can be transferred from person to person or from a place to a person. Transfers can be **primary** (soil from a gravesite embedded into the shoe treads of the killer) or **secondary** (you sit in my car and dog hair from my dog is transferred to your clothing). Quite often, the evidence that is transferred is small or even microscopic in size, adding to the challenge of analysis. Not surprisingly, the most important tool of the forensic trace analyst is the microscope and the analysis conducted is referred to generically as microanalysis.

**Microanalysis** is the application of a microscope and microscopical techniques to the observation, collection, and analysis of micro-evidence that cannot be clearly observed or analyzed without such devices. Microanalysis today generally deals with samples in the milligram (mg) or microgram (μg) size ranges. Microscopes and the techniques to be discussed will be limited to those that employ light in the visible, ultraviolet (UV), and infrared (IR) frequency ranges or use electrons for illumination. Analysis with a microscope may be limited to observations of morphology or involve the collection of more sophisticated analytical data, such as optical properties, molecular spectra, or elemental analysis.

The definition of trace as in the phrase **trace evidence** is more problematical. Historically, criminalistics and forensic sciences used trace evidence to describe any evidence small in size, particularly evidence that would be analyzed with microscopical techniques. In the not-too-distant past, even the analyses of small blood samples and bulk soil or dust samples were considered trace analyses. It is better to define trace analysis as the qualitative or quantitative analysis of the minor or ultraminor components of a sample, where "sample" means an entire submitted exhibit or a subsample of the exhibit. The section of a forensic laboratory where trace materials were submitted generally depended on the historical development of the laboratory. Large laboratories, for example, may have included separate sections for fiber, hair, mineralogy (soil), paint, serology, controlled substances, and firearms analyses. Small laboratories often grouped the sections differently, possibly as chemistry, biology, microscopy, drugs, and ballistics. The types of evidence examined by each area depended on the history of the laboratory. Hair examination cases were sometimes assigned to the biology group, while in other labs they may have been handled by the microscopy unit or chemistry section. Natural and synthetic fibers were assigned similarly to different units.

In this chapter, we will treat all types of classical trace evidence, if examined predominantly by microscopical techniques and methods, as examples of microanalysis. The purpose of these analyses is to determine whether an association of persons, places, and things can be established, and the strength of that association. The association is predicated on the comparison of materials found and the drawing of the conclusion that they are of common origin. The criminalist is drawn to the common origin conclusion, if after having examined the samples in sufficient detail, he or she is unable to establish a forensically significant difference in the materials. The weight of this association is a function of the level of individualization that resulted from his examinations.

# Chapter 16
# Trace Evidence*

*Thomas A. Kubic and Nicholas Petraco*

## Chapter Outline



## 16.1 Instruments of Microanalysis and Sample Types

### 16.1.1 Basic Microscopy

A variety of microscopes are available for use in a forensic laboratory, and they can be used to examine a wide variety of materials. (For a discussion of career preparation for this field, see Sidebar 16.1.) Although many tools are available to the trace analyst, we will touch upon only a few: visible and infrared spectrophotometry via a microscope, and basic scanning electron microscopy (SEM) with energy-dispersive x-ray spectroscopy (EDS). Before delving into these instruments, we will begin with a discussion of the microscope itself and an extension called **polarizing light microscopy (PLM)**. The microscope most likely to be employed first in the examination of evidence is the stereo binocular microscope. It is often employed in the preliminary evaluation of submissions, and for the location and recovery of

* This chapter is based on Chapter 17, "Microanalysis and Examination of Trace Evidence," by Thomas A. Kubic and Nicholas Petraco, as published in the third edition of this text.

**SIDEBAR 16.1. CAREER PREPARATION AND EXPECTATIONS**

To work in trace evidence, solid preparation in several areas is needed, including the core sciences and chemistry. As can be clearly seen in this chapter, skill and experience with microscopes and microscopy are essential and may be difficult to develop in a typical undergraduate curriculum. Because trace analysts work with such a variety of materials, a broad background in many sciences can be useful; for example, knowledge of geology is essential for soil analysis. Trace analysts work many types of cases and, as such, work with a variety of different types of evidence. This is one of those forensic disciplines for which many science degrees could be applicable. A good resource regarding microscopy, a core skill of trace evidence analysis, can be found at the McCrone Research Institute website (www.mcri.org).

microscopic particles and materials from their substrates. Examples are the recovery of fragments of red wool fibers from a victim's sweater found on the denim jacket of a suspect in an assault case and the recovery of glass particles from the jeans of a burglary suspect. This microscope is a compound type. Total magnification is computed by the power of the **objective lens (OBJ)**, or first lens, multiplied by that of the **eyepiece lens (EP)**, or finial lens.

A lens is an optical component that may be composed of one or multiple elements. The stereo microscope is constructed from two similar but separate optical microscopes for observation by each eye simultaneously. The views are separated by a small angle, usually about 15°, so that each eye sees the subject from a slightly different perspective. This generates a three-dimensional image in the same way that our eyes do. Most observations performed with stereo microscopes are carried out with reflected light analogous to how we normally see objects. Figure 16.1 provides a photograph and an optical diagram of a common stereo microscope.

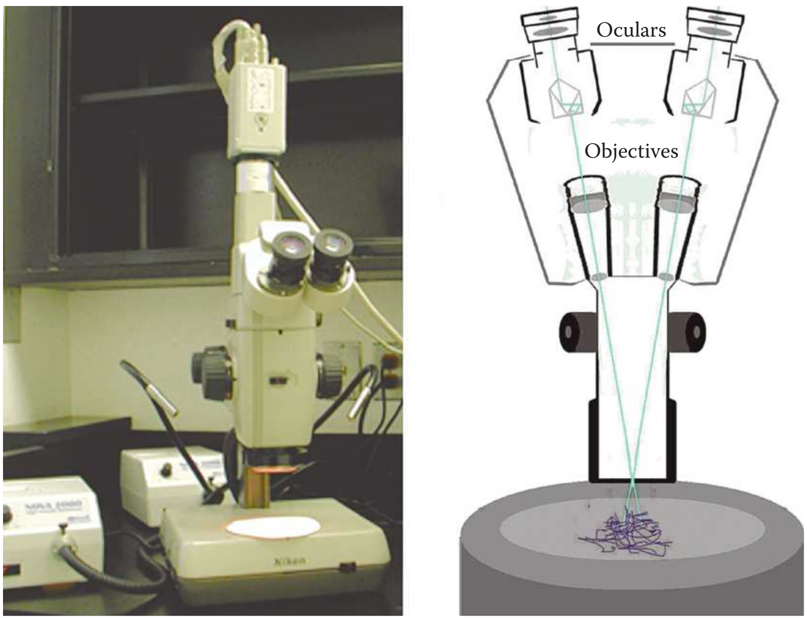



***Figure 16.1*** (Left) A modern stereo microscope with fiberoptic illuminators and trinocular viewing head. The third position is equipped with a television camera. (Right) Optical diagram of a stereo microscope showing the two distinct optical paths that lead to a stereoscopic (three-dimensional) view.

Many significant preliminary and other analytically important observations are made with this microscope. The layer structure of a recovered paint chip including the color of each layer and an estimate of the curliness of a human hair are only two examples. The stereo microscope is also frequently employed for viewing an object while it is being prepared for further, more advanced forms of analyses, such as SEM observation or infrared **microspectrophotometry** (**MSP**).

The second most common type of microscope encountered in the laboratory is the compound binocular microscope (Figure 16.2). Most people are familiar with such microscopes because they are routinely found in schools and medical laboratories. Although this microscope employs two eyepieces (EPs), both eyes see the same image because each eyepiece magnifies an image formed by a single common objective. Most often this microscope employs transmitted, bright-field illumination for viewing. In transmitted light, the sample is transparent or mostly transparent. Most of the illumination passes through the subject and some passes around it.

This microscope is capable of total magnifications in the range of 25 to 1200 times (×) greater than the object, with 40 to 400× magnification commonly encountered in forensic laboratories. The **total magnification (TM)** is the product of the OBJ magnification multiplied by EP magnification: OBJ× multiplied by EP× = TM×; for example, (10× OBJ) × (10× EP) = 100× TM. The most important information obtained with this instrument is morphological, or relating to the structure (**morphology**) of the sample. The use of the microscope allows the examiner to view the exhibit at higher magnification and therefore in more detail. The revelation of detail, in reality, is a function of the **resolving power (RP)** of the microscope, which is related to the **numerical aperture (NA)** of the microscope objective. The numerical aperture of the objective, the first lens of the microscope, generally increases with the

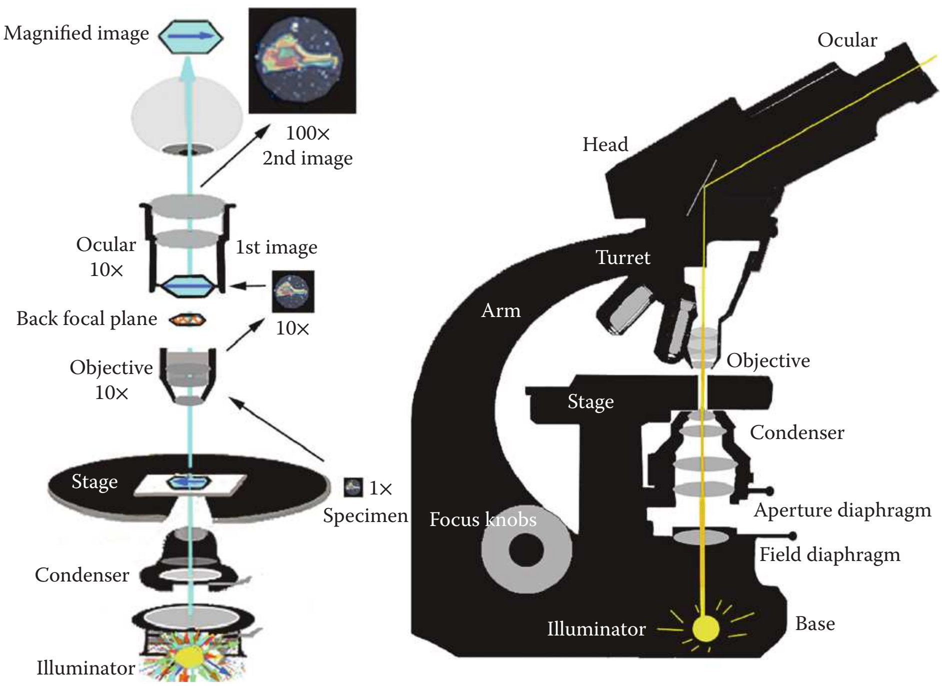



***Figure 16.2*** (Left) A more stylized version of a transmitted light compound microscope showing important optical components and their positions and the position of the specimen and its images. (Right) Optical diagram of a transmitted light compound microscope showing the most important parts and a light path through the microscope from illuminator to ocular.

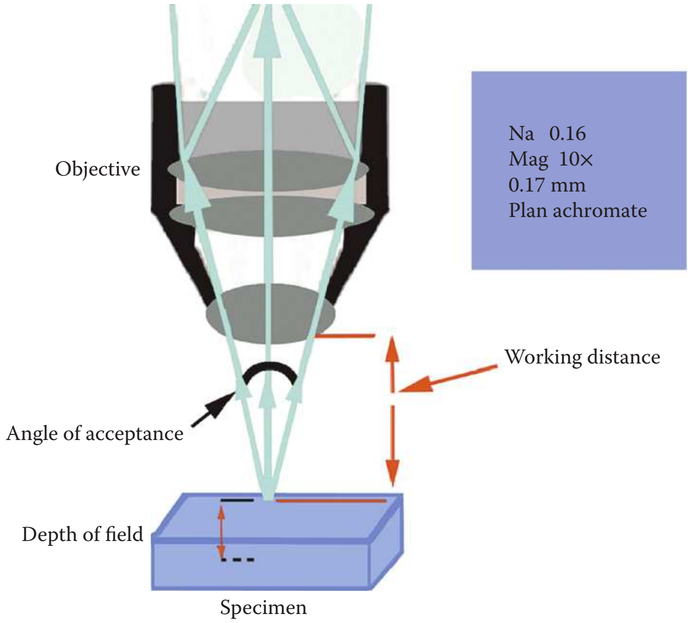



***Figure 16.3*** Stylized drawing of a microscope objective indicating important relationships when an object is focused.

magnification. The NA determines the operational characteristics of a particular objective, its practical use, and the information content of the image produced by the compound microscope utilizing it. The more important of these characteristics and practical considerations are magnification (×), **working distance (WD)**, **depth of field (DF)**, **angle of acceptance (AA)**, numerical aperture (NA), and resolving power (RP). See Figure 16.3.

Of similar importance is analytical information about a sample that can be obtained without the use of sophisticated techniques or the addition of complex accessories to a microscope. Analytical information is obtained by measuring a particular characteristic that is observed. Determining the color and layer structure (number of layers and their order) of a paint chip sample obtained by simple viewing of the object is an example. Valuable additional information can be added to the basic data, if the information is further qualified by comparison to a standard—for example, detailing of the color of a soil by comparing it to a collection of color standards.

Quantification of characteristics such as physical dimensions by analytical measurement can be even more useful. A scale calibrated with a stage micrometer can be placed in the EP of a microscope so that its image is superimposed on the view of the subject, thereby allowing evaluation of characteristics such as length, width, and thickness. This method is known as **micrometry**. The thicknesses of the layers of a paint chip, the average length of scales on a hair (scale count), and the modification ratio of a synthetic fiber determined by viewing a cross-section are examples of quantitative information that can be obtained with a relatively unsophisticated bright-field compound microscope. (See Case Study 16.1.)

Chemical tests that aid in the identification of a material can be performed on micro- and ultramicro-sized samples if the results are observed with a microscope. Chemical color and microcrystal tests employed for the identification of controlled substances and the solubility or reaction of paint to various solvents are routine applications of this technique.

**CASE STUDY 16.1: THE WAYNE WILLIAMS CASE**

Prior to the general acceptance of DNA evidence, many relied heavily on the characterization of hairs and fibers to link a suspect to a scene. One of the most famous such cases was that of Wayne Williams in Atlanta in the late 1970s and early 1980s. Starting in 1979, young black males were disappearing in Atlanta, Georgia, and their bodies were later discovered dumped in wooded areas or near highways and streets. Most of the victims died of asphyxiation. A wealth of fiber evidence was found on the bodies, particularly a yellow–green fiber with an unusual cross-section. In this case, the hair and fiber evidence indicated that the victims had all spent the time immediately before and after their death in the same environment. It also was convincing evidence that the same person was responsible for all of the killings. When a local paper published information relating to the fiber findings, the killer changed his modus operandi (MO) and began stripping his victims completely or down to their undershorts and dumping some into the Chattahoochee River. This change of pattern led to Wayne Williams' arrest in the early morning hours of May 22, 1981. A surveillance team was located under a bridge over the river and heard a loud splash. A car that was driving slowly over the bridge was stopped and the driver, Wayne Williams, was arrested. Two days later, another body was recovered from the river, the odd yellow–green fibers found entangled in his head hair. Subsequent searches of Williams' home and vehicles led to the discovery of the probable sources of the hair—a family dog—and, most importantly, greenish carpet fiber with an unusual cross-section. Williams was tried for two of the murders, and evidence from 10 others was introduced; however, suspicion remains that Williams may have killed others.

### *16.1.2 Polarizing Light Microscopy*

When a compound microscope is fitted with certain accessories, it is converted to a polarized light microscope (PLM). Figure 16.4 shows an example of a PLM, also called a *petrographic microscope*, which is one of the most powerful analytical tools available to forensic science. The basic requirements are that two polarizing elements are positioned in the optical path of the microscope. The first, called the **polarizer**, is placed prior to the sample, normally in the condenser mount just prior to the lenses. The second, called the **analyzer**, is positioned in the body of the microscope, usually in an intermediate accessory tube between the objectives and the viewing head that holds the EPs.

Light is a wave phenomenon. Its characteristics are velocity ($c$), **wavelength** ($\lambda$), and **frequency** ($\upsilon$) related to color; amplitude ($a$) related to brightness; and vibration direction, which is always perpendicular to the direction of propagation (travel). Wavelength and frequency are inversely related: the longer the wavelength, the lower the frequency of vibration. Shorter wavelength light, violet light, and ultraviolet light have higher energy than longer wavelength red light. Normal light is randomly polarized. If the vibration is restricted to only one direction, it is referred to as **plane polarized light**.

Light can become partially or totally polarized in a number of ways, including reflection, adsorption, and propagation through an **anisotropic** material. The earliest devices employed to generate plane polarized light were obtained by the cutting

***Figure 16.4*** Polarized Nikon Eclipse E400 light microscope designed for transmitted light illumination, typically used by journeymen criminalists to examine microscopic evidence. It has a circular rotating stage, strain-free objectives, accessory slot and compensators, a Bertrand lens, and a binocular observation head. (Courtesy of Morrell Instruments, Melville, New York.)

and polishing of particular anisotropic materials along certain directions within a crystal and cementing them together in a certain orientation so that light transmitted along the optic axis of the microscope was plane polarized.

Today, plane polarized light is obtained by the use of polymer films in which the molecules are very highly oriented and have been treated with a dye so that they almost totally absorb light vibrating in all but one direction. This single direction is called the **privileged direction**. A portion of the light in the privileged direction is also absorbed, but this loss of intensity is small in comparison to losses of other directions. These polymer filters are known as Polaroid® filters or films. When two polarizers are placed in such a way that light passes through one and then the second and privileged directions of each are perpendicular, no light will emerge from the second. This condition is referred to as **crossed polars** and results in complete extinction of transmitted illumination. If there is no sample placed on the microscope stage and crossed polars are set, the field of view is completely dark; no light reaches the eye. Figure 16.5 illustrates how this works. A cotton fiber has been mounted on a clear glass slide and is viewed under crossed polars. Notice that the background is completely black; all light has been blocked by the two filters. The cotton fiber, which is between the two filters, interacts with the light enough to generate interference colors and thus be visible.

When an object is placed in the illumination path of a PLM and between the two polarizers, it may affect the vibration direction of the plane polarized light reaching it from the first polarizing element. If this is the case, the material is *anisotropic*, and it will resolve the original vibration's intensity into two perpendicular vibration directions. Each of these resulting rays, except in certain special

***Figure 16.5*** An example of a fiber (cotton) viewed under crossed polars.

directions of propagation, will have a different **refractive index (RI)**, and the difference of these indices is referred to as the **birefringence** (ΔRI). The maximum birefringence is an analytical and identifying characteristic of a material. Both rays travel through the material at different velocities, and this results in a phase shift of the rays when they emerge from the material. This phase shift, known as the **optical path difference (OPD)**, is calculated as the difference in RI (ΔRI) multiplied by the thickness. When the thickness is in micrometers and the resultant OPD is multiplied by 1000, the retardation (R) of the sample measured in nanometers is obtained:

$$R\ (\text{nm}) = \Delta RI \times \text{Thickness}\ (\mu\text{m}) \times 1000$$

When the rays with the two separate vibration directions pass through the second polarizer (analyzer), they are both resolved into rays vibrating in the same direction and are then able to interfere with each other. The amount of interference and the resultant intensity depend on the phase difference between the rays. If the illumination is white light, the various wavelengths interfere in different amounts; certain colors are intensified, and others decreased or even eliminated due to destructive interference. The result is an interference color associated with sample retardation. An analytical working tool referred to as the **Michel–Lévy chart** (Figure 16.6) relates the birefringence, thickness, and retardation properties. If the microscopist directly measures any two components, the third can be easily determined.

Whereas PLM is extensively used to characterize anisotropic samples, many materials are **isotropic**. An isotropic material exhibits only one RI no matter which direction light propagates through the item or what the vibration direction is. Isotropic materials do not affect the vibration direction of light. Vacuums, gases, most liquids, amorphous solids, and isomorphic crystals are all isotropic. Vacuums have none or very few atoms or molecules to react with light. In gases and liquids, the molecules are free to move about with no specific orientation; therefore, light interacts similarly, no matter in what direction it travels.

The same explanation can be employed for amorphous solids such as glass. Although they are solid, the various atoms or molecules of which they are composed are arranged randomly so that light traveling through the material encounters

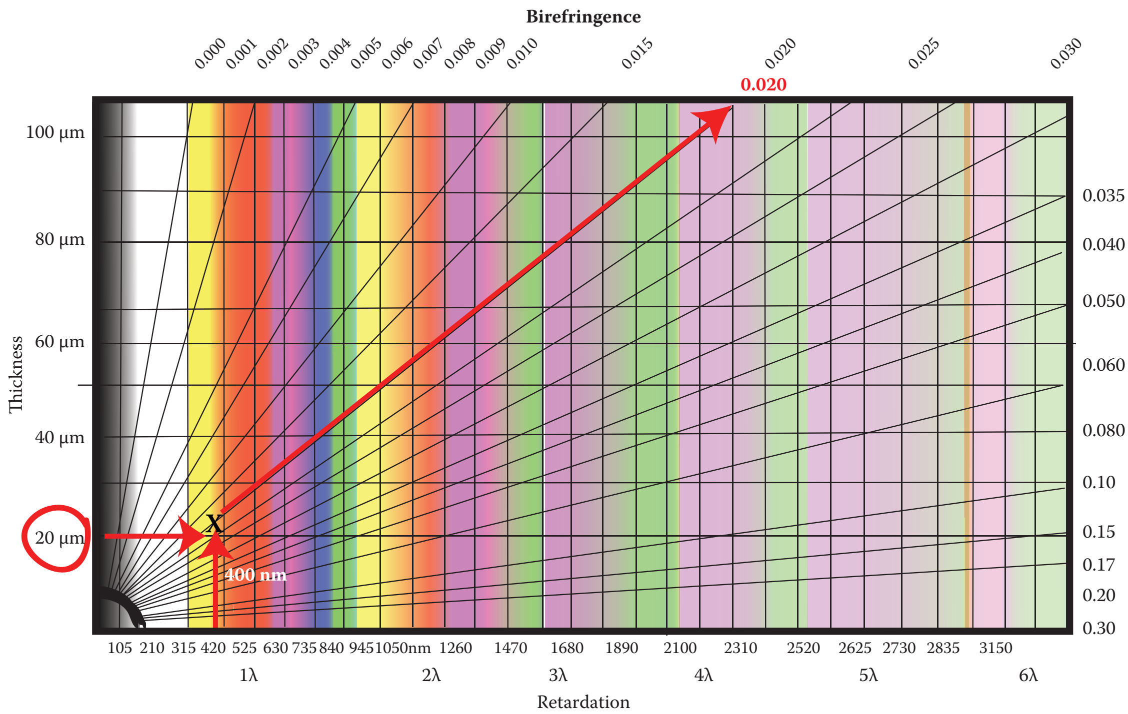



***Figure 16.6*** Michel–Lévy chart.

similar interactions in every direction. In isomorphic or cubic crystals, the atoms or molecules that compose the crystal lattice are arranged similarly along each of the three crystal axes so that light encounters the same atmosphere and interactions in all propagation directions. In either case, there is no difference in refractive indices, meaning that PLM is of little use for these types of samples. For example, if a piece of glass is placed under crossed polars, the field appears dark; the glass does not split the light into two distinct pathways and no **interference colors** are observed.

The RIs of the materials discussed above are characteristics rather than universal constants, meaning that variations in conditions such as wavelength and temperature can influence the RI. By convention, and likely for practical reasons, when data were first organized into analytical data bases, the RI was given at the λ for the sodium D line at 589 nanometers and 25°C. The refractive indices at other λ values for many materials have been compiled. They can be important analytical characteristics, but the most accepted reporting λ remains 589 nanometers (ND). The reported reference temperatures for RIs are more varied because in many substances, particularly certain solids, the RIs may change substantially with temperature. When an RI is reported with a reference temperature and λ, the value is considered an optical constant.

The PLM is the instrument of choice to characterize many forms of microscopic materials, especially because analytical measurements can usually be made nondestructively. These measurements can lead to unambiguous identifications and can aid significantly in the goals of association and individualization; however, PLM is not the only microscopic tool available for trace evidence analysis, and often it is the combination of techniques that is critical for characterization of evidence. A few of these other techniques are described below.

### 16.1.3 Comparison Microscopy

**Comparison microscopes** vary in their design and application to the analysis of evidence. At least one type of comparison microscope will be found in most broad-service crime laboratories. They are all similar in one design principle. They are in reality two microscopes linked by an **optical bridge** so the observer can simultaneously view two independent images in one field, each from a separate objective. The optical bridge often has a mechanical screen to provide a split field of view with a variable point of demarcation. These bridges also allow superimposition of the two images. The lowest total magnifications are found on what are referred to as *macroscopes*. These are like dual stereo microscopes but they lack the three-dimensional imaging common with dual stereo devices. Large tool marks and fabrics are often examined with this instrument using reflected light. Firearms and tool mark examiners (Chapter 14) make extensive use of these types of comparison microscopes. The classical, transmission illumination, bright-field microscopes, and even PLMs are often linked with a bridge so that very small samples, such as hairs and fibers, can be critically examined side by side in the field of view. Many experts suggest that this is the only valid manner of comparison of two pieces of microscopic evidence. It is their position that data recording, sketches, photographs, and even videos are insufficient for the proper, ultimate comparison.

## 16.2 Microspectrophotometry: Microscopes Combined with Spectroscopic Instruments

Microspectrophotometry (MSP) is an area of microscopy that over the past 25 years has become very important. These instruments are commonly found in industrial and academic research laboratories. The technique is almost a required capability for forensic laboratories offering full-service analysis of microscopic evidence. The principal types are visible and infrared microspectrophotometers, and each requires a different instrument design because of the nature of the radiation employed to characterize the exhibit. Some microspectrophotometers employ UV light for imaging and measurement, but they are of less importance in forensic laboratories. We have already discussed these types of spectrometry in the context of forensic chemistry (Section 5), and those fundamental principles apply here as well. As a result, we will not dwell on the spectroscopy aspects of these instruments but rather on the combination of microscopes and spectrometers.

Visible microspectrophotometers (**colorimeters**) lend themselves well to the accurate measurement of color by eliminating the subjectivity that is inevitable when a human observes and describes color. This person-to-person variation arises from individual variations in color perception. These instruments generate transmission, reflection, or absorption spectra from various translucent and opaque samples, and the spectrum is an objective quantitative characterization of color that avoids human subjectivity. Examples of the most common applications are spectra obtained from colored fibers and paint surfaces. These spectrophotometers can be attached to fluorescence microscopes and employed to measure spectra from materials that fluoresce when illuminated with light of sufficient energy.

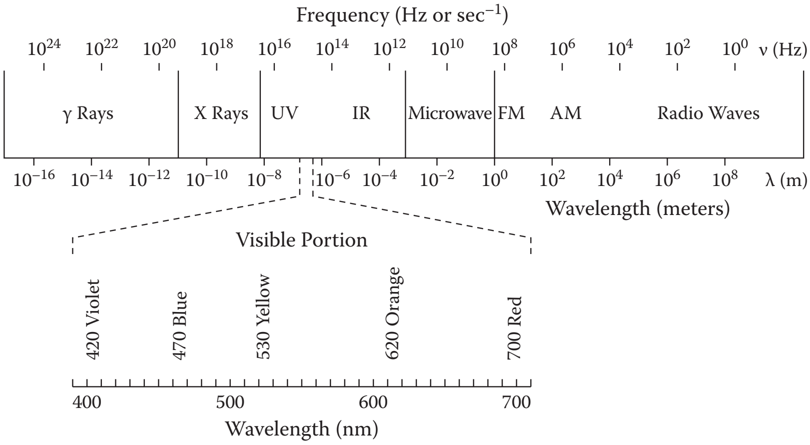



***Figure 16.7*** Infrared region of the electromagnetic spectrum.

Microscopes equipped with colorimeters (visible spectrometers) operate in the range of the electromagnetic spectrum in which humans sense energy as color. There are other ranges of the spectrum that can be utilized as well. The ultraviolet region is one, but forensic instrumentation usually exploits the infrared region of the electromagnetic spectrum (Figure 16.7). Humans sense infrared energy as heat. The infrared microspectrophotometer has become a valuable instrument in modern forensic laboratories. This device is capable of routinely collecting by transmission, reflection, or scattering measurements of the vibrational spectra on tiny samples that could never be analyzed using traditional infrared instrumentation. Organic and inorganic materials or mixtures such as paint can be investigated. These spectra are referred to as *fingerprint spectra* and are valuable sources of structural information leading to chemical classification, generic grouping, and specific identification in many cases. Spectra can also be compared to one another by pattern matching, a concept we first saw in our discussion of arson (Chapter 12).

The spectra obtained by using infrared energy are displayed as a plot of the amount of light absorbed as a function of the wavelength, frequency, or wavenumber (cm$^{-1}$) of the radiation. Put simply, the energy that is absorbed is used to cause motion within a molecule such as vibration of bonds; therefore, infrared spectroscopy is considered to be a form of **vibrational spectroscopy**. We discussed IR spectroscopy briefly in Chapter 11 in the context of drug analysis. The principles are the same here; what is different is the use of the microscope or similar accessories to perform the analysis. These spectra can become quite complex when the molecule consists of three or more atoms. The spectra collected in the range of 4000 to 200 wavenumbers can be used to predict structural patterns or the functional groups contained in the molecules, and the previously mentioned fingerprint spectra of 1700 to 200 wavenumbers can be employed to make an unambiguous identification of a substance. Thus, vibrational spectra are a powerful tool for the forensic scientist to employ for his analysis of drugs, paints, inks, fibers, minerals, and other substances.

Another mode of vibrational spectroscopy is becoming more common in trace evidence analysis by linking a microscope to a spectrometer. **Raman spectroscopy** is based on how light from a source is scattered by the electron cloud of a molecule. The photons that are scattered will either have less energy than the original source photons or more energy than the original. These shifts are directly related to the vibrational energy levels of the bonds of the molecules, and therefore the spectra obtained contain similar if not the same information as infrared spectra.

## 16.3 Scanning Electron Microscopy

The **scanning electron microscope (SEM)** is a powerful addition to a forensic laboratory that permits the viewing of samples at much greater magnification and resolution than is possible by light microscopes. Magnification is possible in the range of 10 to 100,000 times. In forensic labs, the lower magnifications are of more importance with few samples requiring more than 5000× magnification. Very rarely is magnification above 25,000× needed. When the SEM is combined with an **energy-dispersive x-ray spectrometer (EDS)**, the technique becomes even more powerful. The SEM/EDS combination can readily resolve a particle or structure smaller than 1 micrometer in size, while generating spectra revealing the elemental composition of the object.

The principle of operation is that an electron beam is accelerated by a high potential difference, usually 10,000 to 30,000 electron volts. This beam is then focused by the use of electromagnetic lenses to a small beam spot and swept over the sample (Figure 16.8). The beam causes a number of interactions slightly below and at the surface of the sample. **Backscattered electrons (BSEs)** and **secondary electrons (SEs)** are emitted from the surface and converted to an electrical signal by an appropriate detector. The position of the sweeping beam is coordinated with the sweep of a cathode ray tube observation screen, and the intensity of the signal from the detector is converted to brightness on the tube. This results in an image

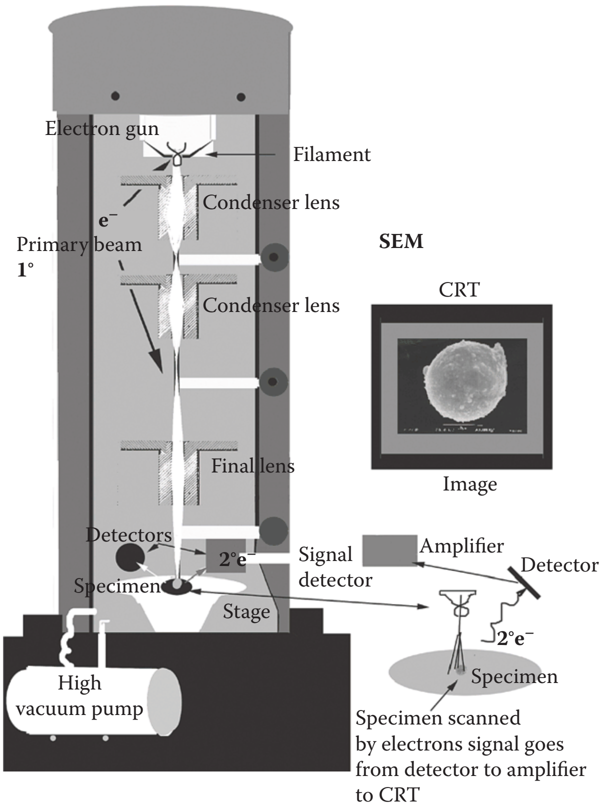



***Figure 16.8*** Stylized representation of a scanning electron microscope showing the source, condenser lenses, beam with its rastering of the specimen, sample position, and detectors. The monitor that displays an amplified signal for the image is linked to the scan generator. The image is a classic gunshot residue particle.

similar to that from a television. The screen size is fixed, and the analyst uses the controls to vary the size of the portion of the sample scanned. The relationship of this scanned area to the viewing screen is the magnification of the microscope.

This electron beam causes many other interactions with the sample, two of which generate x-rays. The first interaction occurs when electrons penetrating the surface of the sample decelerate. This causes the release of energy as a continuum of x-rays and is referred to as the *Bremsstrahlung* or *breaking radiation*. This results in a background upon which an analytical signal is superimposed. The analytical signal is formed when high-energy electrons from the beam strike and cause an inner shell electron from an atom of the sample to be ejected. This results in an unstable electronic configuration for this atom, which is stabilized by electrons from higher level shells filling the voids. When these electrons fall to the inner shells, they need to release energy, which is done via the ejection of an x-ray photon. The energy released is quantized, identifiable to specific atoms, and, hence, useful for qualitative analysis. These specific energies are called *characteristic x-rays*.

The strength or number of x-ray events (counts per second) under given conditions is proportional to the amount of the element present in the sample and thereby leads to methods of quantitative analysis. An x-ray detector is employed to sense these photons and convert them to electrical impulses. Electronic hardware and software sort and display the data so that qualitative and quantitative analyses can be performed on very small particles or limited portions of a sample.

Historically, a SEM required a sample to be contained in a chamber at high vacuum. This caused problems in examining many samples of interest to the crime laboratory. In the last decade, a technique has been developed so that the sample to be studied need not be kept at such great reductions of pressure. This is often referred to as *low-vacuum*, *low-pressure*, or *environmental SEM*. This development made the SEM/EDS system more valuable to the forensic analyst.

## 16.4 Microscopic Evidence and Its Analysis

### *16.4.1 Glass*

Glass, a common type of microscopic evidence, is a reasonably hard, transparent or translucent material composed of fused inorganic materials. Upon cooling, it is **amorphous** in nature and, as noted above, isotropic. Glass is found in many shapes, sizes, colors, and types. Its uses range from containers to optical devices. It has a wide variety of chemical compositions, by both design and happenstance. Variation of its elemental formulas can significantly alter its characteristics and, therefore, often its ultimate uses. For example, glass with high boron content is resistant to thermal shock and is employed in laboratory glassware and cookware. Inexpensive soda lime glass is usually high in sodium and calcium content and is found as containers, windows, and many other products. The addition of high-atomic-number elements increases the RI of glass, causing it to sparkle and serve decorative and aesthetic purposes. Because glass has so many uses, possesses different qualities, breaks easily, and ejects very small fragments in different directions that are retained by garments, it is frequently encountered as **transfer evidence**. Whether flat, container, decorative, optical, or other glass, varying its composition allows it to be discriminated by physical, optical, and elemental characteristics.

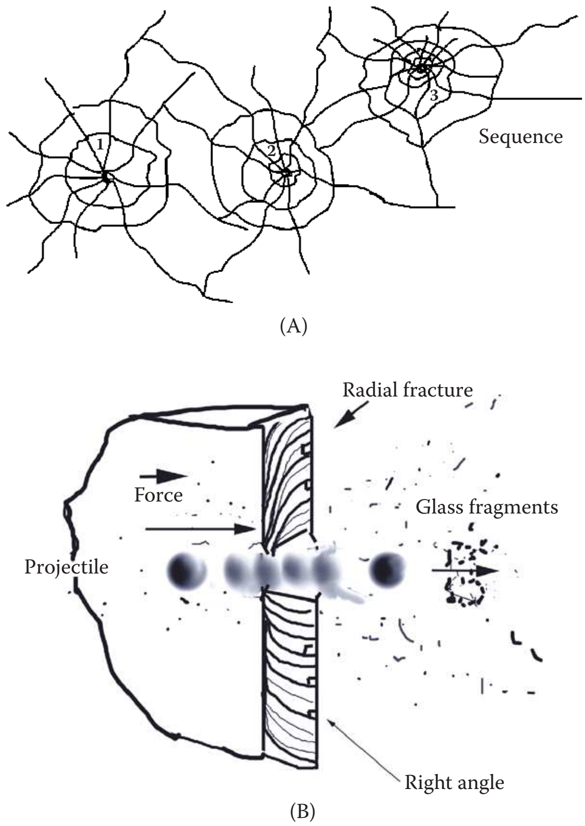



***Figure 16.9*** (A) Radial and concentric fractures, a series of impacts on glass. The sequence is indicated by the terminations of newer cracks at existing fractures. (B) Coring effect fracture, the result of the impact of a high-velocity projectile on glass. The fragmentation, coring, and fracture lines that confirm the direction from which the force originated can be seen.

A first examination of glass should be directed to physical properties that can be evaluated macroscopically or with a stereo microscope. Examination of a broken window can reveal whether the impact that caused the fracture was a low-velocity blunt trauma or a high-velocity point trauma. Figure 16.9A shows breaks in sheet glass caused by multiple impacts. One can observe **radial cracks**, originating from the impact point and propagating away, and **concentric cracks**, which seem to make a circle around the impact point. By noting that some cracks terminate at their intersections with others, one can conclude that terminated cracks were caused by a later impact. Figure 16.9B displays a cross-section of a flat glass impacted by a high-velocity projectile. If enough of the impact point is intact, one will note evidence of the core ejected from the far side of the glass upon impact.

Another fact that can be often ascertained from examination of such fractures is the side from which the force that caused the fracture was applied. When glass fractures, the edges often show characteristics referred to as **conchoidal lines**. The lines shown in Figure 16.10 reveal important information. When the fracture examined is located prior to any concentric crack and is not too far from the point of impact, then the surface opposite that part of the mark that appears to contact the surface at or near a right angle is the side from which the impact force originated. The acute marks point back toward the propagation point of the crack. Careful examination of these characteristics can allow a criminalist to determine whether a window was broken from the inside in an attempt to disguise an "inside job" as a burglary.

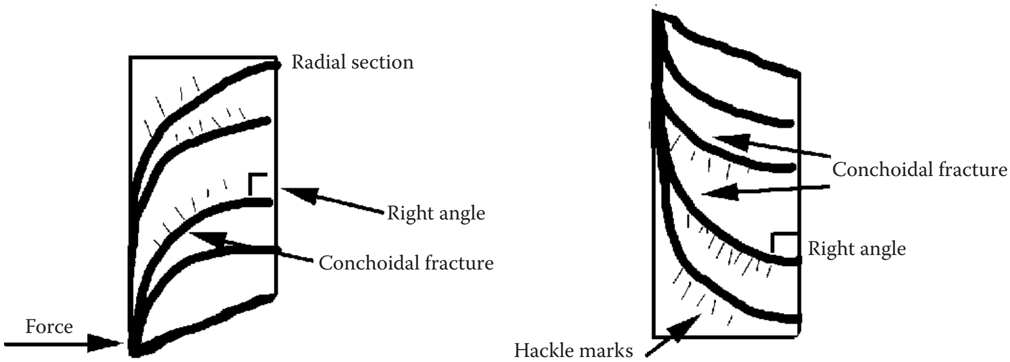



***Figure 16.10*** Expanded view of the conchoidal marks that appear on a fractured glass edge. The smaller hackle marks and the missing core area mentioned in Figure 17.9B are also shown.

When microscopic glass chips are examined in an effort to associate two items, the physical, optical, and elemental properties are all very important. The most discriminating technique has been shown to be elemental profiles. This very time-consuming approach requires expensive instrumentation and highly trained analysts. Physical examinations and measurement of optical properties may eliminate samples as having possible common origins. Because these measurements are more easily conducted, they should, in most cases, be performed first. If they are not capable of discriminating the samples and the values of the data obtained are common, then the evidentiary value of the match obtained is weak and more sophisticated analyses are dictated.

Some physical observations that should be undertaken are thickness, color, uniformity, curvature, and surface conditions, such as tinting, soiling, and imperfections. Flat glass should be examined with an ultraviolet light so that float glass can be discriminated from double-ground and polished plate. Float glass is manufactured by "floating" molten glass onto the surface of a bath of melted tin. Some of the tin diffuses into the glass and results in a product that fluoresces when excited by ultraviolet light. The pale blue to yellowish glow does not appear on both surfaces.

If the recovered glass evidence consists of small fragments, many of the aforementioned tests may be precluded; however, the optical properties of small fragments can be successfully evaluated, and these characteristics can be reasonably discriminating. Small fragments of glass can be removed from larger pieces and the optical properties measured. The most significant property is the RI. The RI values of small glass chips cannot be measured directly but may be measured indirectly by one of the immersion methods based on submersion of a sample in a liquid, usually referred to as oil even if it is not organic in origin. Employing one of the **immersion methods** allows an analyst to determine when the RI of the sample matches that of the liquid medium at a given $\lambda$, and then he or she measures the liquid or reports the predetermined RI of that liquid. When the RI of the sample is near or matches the RI on the medium, the contrast of the sample will be low and it will be difficult to see in the liquid.

When the RI differs by an appreciable amount, the contrast will be significant and the sample will be easy to observe. See Figure 16.11 for examples of high and low contrast. At first impression, one might not want to attempt this measurement as it seems to require good luck or extended effort to find the matching liquid by trial and error. However, a number of methods can determine whether the liquid medium or the solid sample has the higher RI, thereby giving direction for the next choice of liquid. Oblique illumination, dispersion staining color, and the movement of the **Becké line** are the most common techniques. The most popular is the Becké line method. A microscope is focused on the sample and the focus is then raised. The

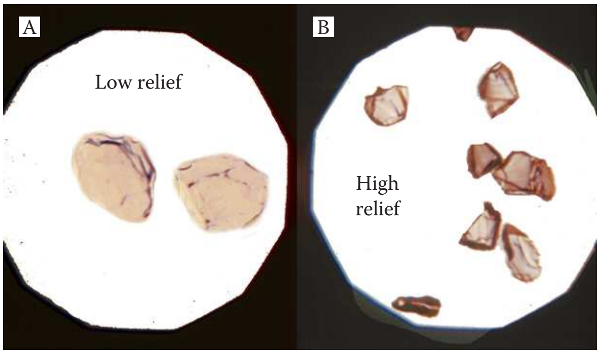



***Figure 16.11*** An example of low contrast (relief). (A) This is the appearance when the RI of a sample is similar to that of the immersion medium. (B) An example of high contrast (relief) that appears when the RI of a sample is significantly different from that of the immersion medium. Note that which RI is higher does not matter; the contrast principle remains the same.

distance between the sample and the microscope objective is increased. When this is done, a halo or brightness near the edge of the sample, the Becké line, will move into the material of greater RI, whether it is the sample or the mounting medium. Figure 16.12 shows examples of the appearance of a Becké line in and out of a sample. When this measurement is made with a well-maintained, quality microscope, the accuracy of the measurement can be in the area of 0.0005 RI units. Better accuracy is required for advanced criminalistics work. This can be accomplished by a number of methods, all of which require a phase-contrast microscope that makes detection of the minimum contrast or match point more accurate.

Improvements in accuracy and precision result from employing a phase-contrast microscope, monochromatic light, and a well-characterized oil, where the RI is varied with a microscope heating stage. This approach is based on the fact that as temperature increases the refractive index of materials such as immersion oils changes. An instrument can be calibrated such that the RI is known at every temperature used in the heating and cooling cycle. Known as the **single-variation method**, the RI is determined by recording the match temperature and employing the calibrated –dn/dt of the oil to calculate the RI of the sample. The **double-variation method** employs a heating stage to maintain oil temperature, and a monochrometer is employed to determine the match wavelength. The oil temperature is then changed and the match $\lambda$ determined again.

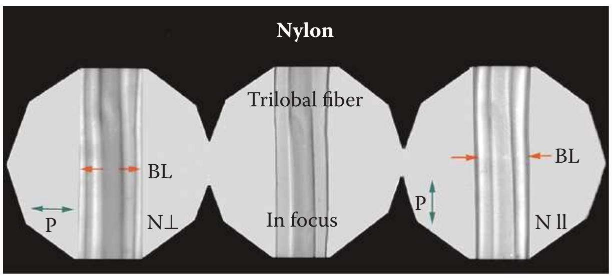



***Figure 16.12*** Fiber Becké line movement. (Center) A nylon fiber in critical focus, mounted in a medium of RI 1.53. (Left) When this fiber is viewed in plane polarized light and oriented so the microscopist is viewing the perpendicular (cross-wise vibration) RI of the fiber, the Becké line or bright halo will move into the medium when the focus is raised. (Right) Photomicrograph of the view with the parallel (lengthwise vibration) RI of the fiber, indicating the movement of the Becké line into the fiber when the focus is raised. Because the same immersion liquid is used in both cases, the sign of elongation of the fiber is readily determined to be positive; that is, the RI is greater along the length.

The above methods have the ability to determine RI with an accuracy of 0.0001 and a reproducibility of approximately 0.00005. Today's modern manufacturing methods produce glass with significantly less RI variation than in the past. This has necessitated improvements in the measurement of the optical properties and the adoption of elemental profile analysis methods for testing glass samples.

An automated method for determining the match point of a glass chip employing commercial instrumentation has been available for over a decade and is called **GRIM (glass refractive index measurement)**. A GRIM instrument employs computer control of the heating stage and a video detector to determine the match point (i.e., the point at which the glass is no longer visible). Along with automating the calculation, the main advantage is removal of the operator's subjectivity in determining the match point. With this instrument, measurements of RI can be made with an accuracy of 0.00005 and precision of 0.00002 or 0.00003.

### *16.4.2 Hairs and Furs*

Hairs and furs are additional examples of evidence types amenable to microscopic analysis. They are natural fibers of animal origin. In this section, we will define hairs as animal fibers that originate from humans, while furs originate from other species. Hairs can generally be grouped by racial origin and often body location. Hair examiners can often conclusively eliminate a person as a source of a hair, but rarely can an examiner absolutely associate a hair sample to a given individual. When this occurs, it is usually based on a factor or factors beyond those characteristics observable and measurable with a light microscope. Today's DNA technology is an example of a factor that may allow such an unequivocal association. Certain rare diseases, when detected and combined with microscopic observations, can similarly result in an unequivocal association. DNA testing requires a hair exhibit to have cellular material from which DNA can be extracted. This is not always possible, in which case the criminalist must revert to microscopic methods.

Furs can generally be classified by species with a microscope, but subclassification can be problematic unless an extensive reference collection is available. Even then, specific identification is not always possible. Some steps toward individualization are possible with animal furs, but these are not well developed; however, basic characteristics such as color, length, and curliness can be valuable.

Hairs and furs are principally composed of keratins, which are sulfur-containing proteins that are interlinked to form stable fibrils and pigment composed of **melanin**. Trace metals are also present, having been deposited in the fiber during its growth stage or collected from contamination in the environment. One of the more important linkages is the disulfide bond that is present between sulfur atoms in adjacent keratin chains. The shaft of a growing hair extends out of the skin, with the root imbedded in this tissue. The lower end expands to form the root bulb where growth takes place at the papilla. Except at this point, the fibers are composed of dead cornified cells. The root portion is referred to as the **proximal end**. The tip away from the root is known as the **distal end**. After a period of growth known as the **anagen stage**, the hair or fur will enter the **telogen** (dormant) **stage** and eventually be sloughed from the body. The intermediate or transition phase is known as the **catagen stage**.

The structure of a hair can be considered to have three parts, similar to a graphite pencil. The center portion is known as the **medulla**; it is usually amorphous and vacant of material in human hair. It appears dark when the exhibit is mounted in a

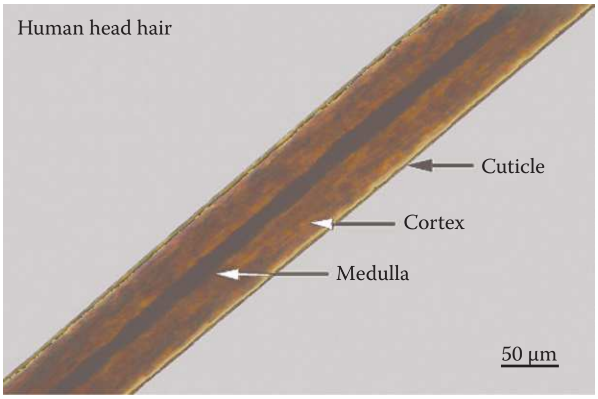



***Figure 16.13*** Photomicrograph of a dark brown human head hair. Note the three principal parts: innermost medulla, cortex, and outer surface cuticle.

liquid and viewed via a microscope. In animals, the medulla contains cells arranged so that their appearance varies in a manner that assists in species determination. The next and predominant portion is the **cortex**, which corresponds to the wood part of a pencil and contains many important microscopic features, such as pigment, tiny air pockets called **cortical fusi**, and **ovoid bodies**, which are especially important in human hair examination. The third outermost portion of the hair, equivalent to the painted area of the pencil, is the **cuticle**. This consists of a layer of scales covering the shaft in such a way that they always point away from the proximal end and toward the distal end. The basic structure of a hair is shown in Figure 16.13.

The scale structures can be divided into three basic types. Coronal or crown-like scales resemble stacks of paper cups and are characteristic of very fine hairs. This type of structure is normally found on small rodents and bats and rarely in humans. Spinous or petal-like scales are triangular in shape and usually protrude from shafts. They are not found on humans; they are found on cats, seals, and near the roots on minks, among others. Imbricate or flattened scales overlap, similar to shingles on a roof. They are found on humans and many other animals. The general appearances of various scale types can be seen in Figure 16.14A. The medulla of a hair can be continuous, discontinuous, or fragmentary, or it may not be observable. In nonhumans, the structures are usually regular and well defined. The principal types are (1) **uniserial ladders** and **multiserial ladders** found in rabbit hairs, (2) lattices found in the deer family, and (3) vacuolated or cellular types. The shapes vary and are commonly found in many animals. See Figure 16.14B for descriptions of three medulla types. Usually for fur examination, the determination of species and the development of basic information such as color are sufficient for the analysis.

The microscopic examination of hairs of human origin can produce an extensive amount of additional information. The racial origin of hair can be determined and classified as Caucasian, Negroid, Mongoloid, or of mixed origin. The body locations from which the hair originated can be determined include the head, pubic area, limb, beard, chest, axillary, and other areas. After the factors cited above have been determined, other activities of value in associating a recovered hair with an individual include careful examination of the characteristics of the tip, root, diameter, scales, pigment, medulla, and cortex; detection of artificial treatment, damage, and the presence of vermin or disease; and determination of the method of cutting.

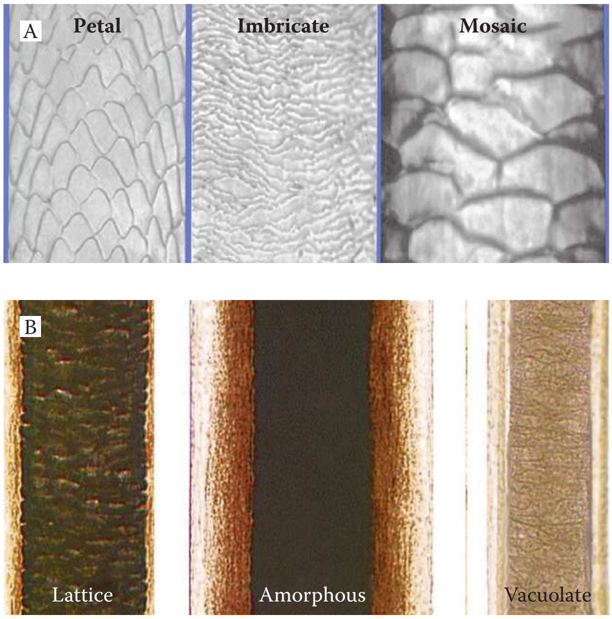



***Figure 16.14*** (A) The petal, imbricate, and mosaic types of scales that comprise the cuticle are clearly differentiated. (B) Three of the different kinds of medullas found in hairs and furs are displayed.

## *16.4.3 Fibers*

Fibers constitute another common class of microscopic transfer evidence. Because they are multitudinous in major classifications and generic subtypes, are physically different, processed in many ways, transfer easily, and have significant persistence, they are treated as valuable forensic microscopic evidence. One manner of grouping fibers is as animal, vegetable, or mineral. Other categories include naturally occurring, manufactured, and synthetic.

Natural fibers are those that have not been greatly altered in physical composition or characteristics by processing. Coloring and treatments that improve merchandising or performance do not change the classification. Manufactured fibers are produced from fiber-forming substances that can be synthetic polymers, transformed or modified natural materials, and glass. Processing is necessary to form the fiber. Synthetic fibers are manufactured from synthesized chemical compounds, such as nylon, that are then formed into fibers.

Although fiber evidence can be examined by powerful instrumental techniques, the use of microscopy for initial examination and collection of the first analytical data is the accepted forensic procedure. A number of the microscopes mentioned in the first portion of this chapter are routinely applied to fiber analysis.

A stereo microscope is first employed, and the size, crimp, color and luster, possible cross-section, damage, soil, and adhering debris are documented. Initial classification may be performed. If the exhibit is a yarn, thread, or fabric, additional information is recorded. This is followed by examination with a PLM from which a wealth of additional information can be obtained.

Examination of the fiber is carried out under crossed polars and also with plane polarized light. It should be obvious that the morphological characteristics of the fiber, no matter how they are observed, are important. The appearance of natural vegetable fibers is noteworthy. Certain characteristics allow identification of the source plant. A number of characteristics can be determined with crossed polars.

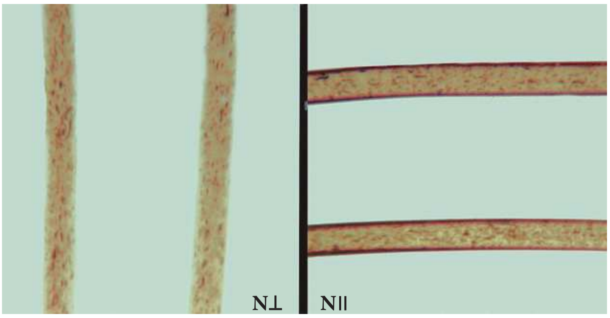



***Figure 16.15*** Photomicrograph of a synthetic polyester fiber mounted in a medium of approximately 1.66 RI. The fiber is displayed in two orientations in a PLM employing plane polarized light. The vibration direction of the light is left to right (east to west) in both representations. The RI of the fiber with the vibration direction crosswise (left) to the fiber is nearer the medium, rendering the internal characteristics more visible. When a fiber is parallel to the vibration direction of the light its index ($N_D$), is more distant from the medium and generates more contrast at the periphery of the specimen.

The first is whether the fiber is isotropic or anisotropic. Almost all isotropic fibers are made from glass. A few synthetic fibers appear to be isotropic because their birefringence (ΔRI) is so small and the fibers are not very thick.

The retardation of anisotropics is estimated and then determined with greater accuracy by compensators. The relative refractive indices can be estimated so that the **sign of elongation** is determined. If the thickness can be measured accurately, the ΔRI—a valuable analytical parameter—of the fiber can be calculated. When viewed with plane polarized light, the natural color is determined, and any dichroism or variation of color due to the selective absorption of light depending on the light's vibration direction can be recorded. With plane polarized light, the RI values of the fiber with light vibrating parallel and perpendicular to its length can be measured. These parameters, known as $\mathbf{N}_{\parallel}$ and $\mathbf{N}_{\perp}$, are important analytical parameters found in tabulated databases from which generic and sometimes subclass and brand can be determined.

Figure 16.15 displays the difference in appearance of a fiber, depending upon its orientation when viewed in plane polarized light. This is due to the differences in RI. If a sample can be cross-sectioned, very important data can be collected, especially about synthetic fibers. Size and shape can be determined unequivocally, and the **modification ratio (MR)** is an aid in brand identification. The MR is the ratio of the smallest circle that contains all the lobes of a noncircular fiber compared to the largest circle that can be drawn in the core of the fiber. Cross-sectional shape alone can aid in determining the manufacturer and the end use of the fiber, such as in clothing or carpets.

An analyst who is most interested in the fine surface structure and requires a higher resolution image of a fiber may decide that the advantages of SEM observation are warranted. Along with the advantages mentioned earlier, SEM observation also allows a sample to be viewed with a greatly increased depth of field. This can be very useful when examination of a piece of textile is the task or a more in-depth study of fiber morphology is desired.

The microprobe abilities of SEM/EDS that allow the determination of elemental composition can also assist the criminalist in identification and comparison. The presence of chlorine in a preliminarily identified acrylic fiber indicates that the fiber is a modified acrylic. The detection of appreciable amounts of titanium dioxide in a fiber is indicative of the mineral being added to the fiber to act as a **delusterant**. When tin and bromine are found in a fiber in which they are not part of the expected chemical formulation, the presence of fire retardant is suspected. When fibers are colored by incorporation of inorganic pigments in a polymer prior to extrusion, the elemental profile determined by x-ray spectra can aid identification.

The abilities of microspectrophotometers have been discussed. They are frequently employed in forensic fiber analysis and comparison. The visible spectrometer is employed to unambiguously and objectively determine the color of an exhibit. Infrared spectra determined from fibers as small as 1 millimeter long allow confirmation of the determination of generic class established by the PLM. Some fiber classes can be classified into subgroups by their infrared spectra. The collection of dichroic spectra of fibers is suggested as a method of detecting possible differences in submissions. The application of micro-Raman spectrometry to fiber analysis may allow an analyst to identify the dye in a fiber.

All of these methods are nondestructive; however, situations may arise that call for the application of other methodologies to strengthen evidence obtained by a comparison. There is little objection to employing destructive methods when an analyst has in his custody sufficient samples of the questioned and known samples. Pyrolysis gas chromatography, often employed with mass spectrometry, can add to the discriminatory ability of an analysis. Likewise, the application of elemental analysis to determine the trace elemental profiles of samples is carried out on occasion. Dye identification and comparison can be attempted by extraction of the dyes from the fibers and analysis by thin-layer chromatography (described in Chapter 11) or liquid chromatography (described in Chapter 10).

The information that can be obtained from the application of the methods mentioned and others for the forensic analysis of even micro-sized samples of fibers can be overwhelming. The reader is reminded that nondestructive techniques should be employed first, and before that a judicious determination of what information is required or desired should be made.

### *16.4.4 Paint*

Paint samples are a major portion of micro samples submitted to crime laboratories. This class of transfer evidence can play an important role in investigations and possible prosecutions. Forensic paint analysis and comparisons for common origin are distinguished from those performed by industrial laboratories by the size of the samples submitted for characterization. Forensic samples are not pristine; they are subjected to uncontrolled environmental and collection effects.

Paint submissions usually involve vehicular accidents where contact between two objects is sought to be established or investigative information such as make, model, and color of a vehicle involved in a hit-and-run is desired. Less often, paint from an architectural source is submitted. These exhibits are usually related to investigations of crimes against property. On some occasions, samples of an artistic nature are submitted. Any of these submissions may also involve crimes of a much more serious nature, such as assaults, rapes, and homicides.

Paints are applied for protective value, aesthetic purposes, or both. In this discussion, paint will include a range of materials from thin, translucent stains to heavy, opaque films. Basically, paint is composed of three generic components. The **vehicle** is the binder that holds all of the components together and is usually of polymeric nature, consisting of natural or synthetic resins. The binder can form a surface film in a number of ways. When the film forms by the simple evaporation of the solvent system of the liquid, the paint is normally classified as **lacquer**. Characteristic of lacquers is the fact that they re-solubilize when subjected to many organic solvents.

When the film is formed by chemical cross-linkage of a number of its components, it is usually referred to as **enamel**. The cross-linkages can be initiated by elevated temperature, oxidation by exposure to oxygen in air, chemical reactions of the components or special initiators, or a combination of these factors. Latex paints form films by the coalescence of dispersed latex particles upon loss of water. These working definitions are not exclusive, and combinations of the film-forming mechanisms are common.

**Pigments** supply paint with color, hue, and saturation. Pigments may be organic or inorganic. Blues and greens are predominantly organic, whereas whites, yellows, and reds are inorganic. This is not a strict rule, and crossovers and mixtures are common in modern formulations. Pigments are expensive, and manufacturers seek to minimize their use to lower costs. **Extenders** are generally less expensive inorganic materials that are added to the paint to increase its solid content and, thereby, its opacity and hiding ability. Other advantages may ensue by their addition. A number of materials, such as titanium dioxide—not inexpensive but known for its hiding capacity—can fill the roles of pigment and extender.

Of equal importance in paint formulations, although not principal parts by concentration, are **modifiers**. They can affect the resultant film's durability, gloss, flexibility, hardness, resistance to ultraviolet radiation, and other characteristics. Other modifiers are added to aid in manufacturing, application and drying, or film formation.

The chemical compositions of the major components and modifiers can be evaluated individually or in combination by a number of chemical, microscopical, and instrumental methods. The size and condition of the sample and the information needed will guide the forensic analyst in choosing methods and techniques to be employed for the physical and chemical analysis of paint evidence. The thrust of analysis is the attempt to find forensically significant differences in the questioned and known samples so that a hypothesis of common origin is rejected. However, differences in some physical and chemical characteristics have been found in samples of paint known to originate from the same source. It is the responsibility of the paint examiner to evaluate the meaningfulness of any differences so that a false exclusion does not result. It cannot be emphasized strongly enough that adequate documentation is necessary at every point of the examination, from sample collection and submission to the final test performed and the conclusion reached.

How paint evidence is collected can be critically important for determining the value of a forensic analysis. When in doubt or when the retrieval of a sample may require specialized skills or equipment, it is best to submit the entire object to the laboratory. Smeared samples that may contain intermingled materials from a number of layers are problematic and the foregoing suggestion should be followed. When this is impractical, the paint must be removed for submission. A general rule is to collect at least one complete sample from an area very near, but not exactly adjacent to, the area of alleged contact. Additional samples from the known should also be collected, packaged separately, and submitted. The undermost layer of a paint chip, especially in an automotive paint sample, can be very useful and care should be taken to ensure that known samples contain this layer. When collecting samples, especially knowns, keep in mind the possibility of a **physical match**, which is the strongest association that can be established. Care should be taken not to alter or damage the sample's shape or surfaces.

Because a physical match is the most conclusive, the first part of a paint examination should be an attempt to establish it. A physical "jigsaw" fit of edges or a match of surface striae on the questioned and known samples is strong evidence. The quantity and quality of the characteristics that match should be sufficient to establish uniqueness. These examinations are generally conducted macroscopically, using an illuminated desk magnifier, a stereo microscope at its lower range of magnification, and reflected light illumination at various incident angles.

If a physical match is not attained, the layer structure order, color, thickness, and other details should be documented. Some manipulation of the sample may be necessary in order to collect the needed information in sufficient detail. Angle cuts and thin sectioning with a clean (new) scalpel blade can clearly reveal the layer structure. It may be necessary to embed the sample in a resin to obtain high-quality thin sections. Embedded samples make it possible to grind and polish a sample so that fine physical details such as pigment size and distribution can be evaluated by higher resolution microscopes.

If a sample is sufficient, destructive tests based on chemical reactions can serve as sources of additional data. The dissolution, swelling, or generation of colors with various solvents or reagents is informative about the possible identity of resins, pigments, and extenders. These tests can be performed in a porcelain spot plate or small disposable test tube, or on a glass microscope slide. Observing the tests with a microscope allows them to be successfully performed on micro-sized samples. Because the pigments and extenders found in paint have been ground to such a small size, their unambiguous identification by use of a PLM is beyond the expertise of all but the most highly trained microscopists; therefore, most analysts will resort to various instrumental techniques to further characterize samples.

Infrared microspectrophotometry is routinely employed for paint analysis. Transmission measurements can be obtained on thinly sliced or rolled samples and by compressing the paint in a diamond cell. Attenuated total reflection objectives allow for the collection of spectra from the surface of a paint sample without the need to prepare a thin specimen. The recent introduction of commercially available Raman microspectrometers added to the information that can be obtained from a paint sample. The analysis of paint by SEM/EDS is reasonably straightforward after sample preparation is complete. The availability of the new eco-SEMs eliminated most sample preparation problems and allows most samples to be placed directly into a chamber and analyzed. Not only can the layer structure be further elucidated by the higher resolution and the atomic number contrast available, but also elemental analysis can be performed with the x-ray spectrometer attached to the instrument.

Other methodologies too numerous to mention may be applied in specific situations, and the techniques discussed above should not be considered exclusive. They are, however, those most commonly employed, but a prudent examiner should always keep an open mind to innovation. Additional applications of microscopy can be used for evidence collection and evaluation.

### *16.4.5 Soils*

Soils are complex mixtures of materials of mineral, animal, and vegetable origin at various levels of change and decay. Many of the components are common. Some have been deposited by natural forces, while others have been delivered through the intervention of humans. The great variation of these combinations leads some to believe that soil has a unique composition in any given area and changes detectably every few feet. Light microscopes, particularly PLMs, lend themselves well to the investigation of forensic soil samples. Many other techniques, some instrumental, are also applicable but will not be covered in this section. Physical characteristics, such as color, pH, and particle size, can be relevant. As a very basic introduction to this topic, one could consider the pollen content and mineral assemblages present in an exhibit. **Pollens** can be readily identified by their morphology using light microscopy or SEM. Although pollens are small and can be windblown, any reasonable concentration of a certain type can be a strong indicator of a location that becomes more specific when a number of pollens are identified. The reader should consider other uses of pollen analysis, such as for pollen detected on autos parked near certain plants or on the clothing of a burglar who made contact with a number of flowering plants during entry through a window.

The identification and quantitative estimation of the mineral content of soils have long been accepted as indicators of location. In these analyses, the more common minerals referred to as the light fraction are considered much less important than those of greater density. Separations are first conducted, and then the minerals are identified by colors, shapes, and optical properties such as RI values and birefringence. When all the microscopically obtained data and those developed by other methods are considered, it is possible for a trained examiner to supply valuable investigative and probative information concerning soils.

### *16.4.6 Gunshot Residue*

**Gunshot residue (GSR)** analysis should be mentioned whenever SEM is considered in the discussion of forensic analysis. We discussed guns, firearms, and how GSR is created in Chapter 14, but here we will focus on how it is analyzed as trace evidence. We define GSR as a mixture of organic and inorganic materials originating from the projectile, cartridge case, propellant, and primer that emerge from the barrel and other openings of a firearm and are deposited on the hands, hair, face, or clothing of persons in close proximity to the weapon when it is discharged. To avoid confusion, we will not consider these materials when they are deposited on the victim and their residue is used to determine weapon-to-target distance. Such materials should be called "firearm discharge residues" or "muzzle blast." Analysis of firearms discharge residue and distance determinations will not be considered here.

The goal of GSR residue analysis is to determine that a residue is indeed GSR and to ultimately place the discharging firearm into the hands of a shooter. This final goal remains to be accomplished. Reports may state, "… indicates that the individual recently discharged or was in close proximity to a discharging firearm." Classically, the analytical problem has been approached by collecting samples from the hands of a suspect and analyzing them by a bulk elemental analysis method.

Currently, the method of choice for the analysis of GSR targets the particles formed when a weapon is fired. The particulates are collected and analyzed using SEM. Specifically, the subject is sampled with a SEM stub coated with a sticky substance that collects the GSR, which is in the form of particles. These particles predominantly range in size from 0.5 to 2 μm, with some as large as 10 μm. The particles are located by viewing in an SEM employing a backscatter electron image (BSE) formed by the higher energy electrons that are elastically scattered from the sample. BSE signals are sensitive to differences in atomic number, with higher average atomic number materials appearing brighter on the instrument's screen. This allows the operator to either manually ignore duller particles or set a brightness threshold for further analysis by the computer automated instruments.

The brighter particles are analyzed for their elemental content by EDS, and those with particular compositions, especially if spherical, are classified as GSR or probable GSR. Particles containing barium, antimony, and lead or those containing barium and antimony are considered characteristic of GSR. Other combinations such as lead and antimony are indicative of GSR. Other compositions and methods of classifying

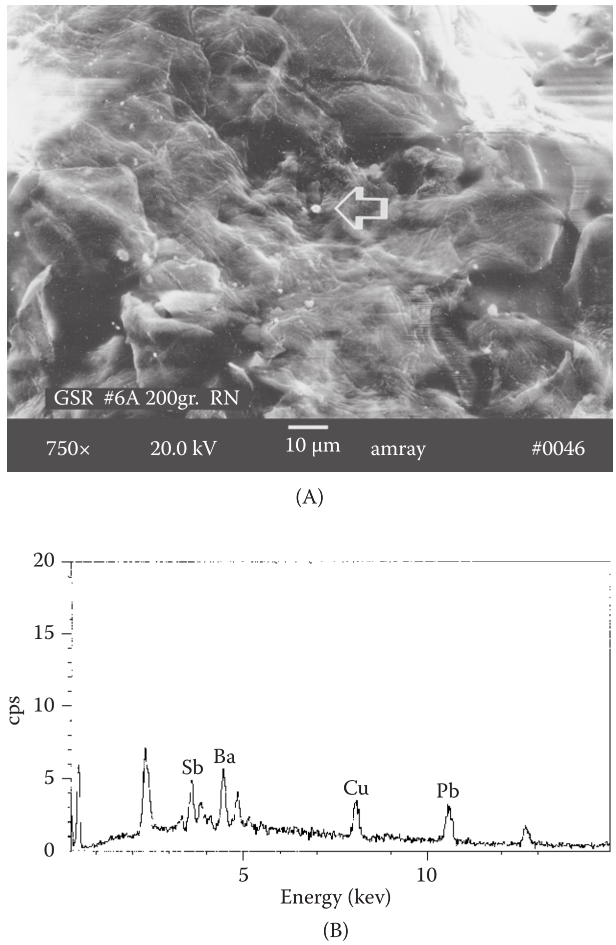



***Figure 16.16*** (A) Adhesive lift with GSR particle. This photomicrographic indicates the bright GSR particle (arrow) found on human skin. (B) The EDS spectra of a classic GSR particle with Pb, Sb, Ba, and Cu from a projectile jacket.

the particles are acceptable, but they are too lengthy to be discussed here. Figure 16.16 shows a photomicrograph of a GSR particle and its spectra. Practitioners' opinions vary concerning the number of particles and composition required to determine that a sample is truly GSR and did not originate from environmental contamination. Consideration should be given to the location from which the sample was collected—for example, the web of the hand or the palm. The goal of unambiguously placing a particular weapon into the hands of a specific individual still remains to be attained. Further study and advances in techniques continue to be pursued.

## Chapter Summary

Trace evidence incorporates paint, glass, soil, plastic, tape, and everything between. Analysis can include searching for a physical match to pattern matching using sophisticated instrumentation such as infrared and Raman microspectrophotometry. The common theme is trace evidence, which implies a small size, and as a result, the microscope plays the central role in trace evidence analysis. A trace analyst must be skilled in this art as well as the art of comparison to link evidence to a possible source.

## 16.5 Review Material: Key Concepts and Questions

### 16.5.1 Key Terms and Concepts

Amorphous
Anagen phase
Analyzer
Angle of acceptance (AA)
Anisotropic
Backscattered electrons (BSEs)
Becké line
Birefringence
Catagen stage
Colorimeters
Comparison microscopes
Concentric cracks
Conchoidal lines
Cortex
Cortical fusi
Crossed polars
Cuticle
Delusterant
Depth of field (DF)
Distal end
Double-variation method
Enamel
Energy-dispersive x-ray spectrometer (EDS)
Extenders
Eyepiece lens (EP)
Frequency
GRIM (glass refractive index measurement)
Gunshot residue (GSR)
Immersion methods
Interference colors
Isotropic
Lacquer
Medulla
Melanin
Michel–Lévy chart
Microanalysis
Micrometry
Microspectrophotometry (MSP)
Modification ratio (MR)
Modifiers
Morphology
Multiserial ladders
$N_{\parallel}$ and $N_{\perp}$
Numerical aperture (NA)
Objective lens (OBJ)
Optical bridge
Optical path difference (OPD)
Ovoid bodies
Physical match
Pigments
Plane polarized light
Polarizer
Polarizing light microscopy (PLM)
Pollen
Primary transfer
Privileged direction
Proximal end
Radial cracks
Raman spectroscopy
Refractive index (RI)
Resolving power (RP)
Scanning electron microscope (SEM)
Secondary electrons (SEs)
Secondary transfer
Sign of elongation
Single-variation method
Telogen stage
Total magnification (TM)
Trace evidence
Transfer evidence
Uniserial ladders
Vehicle
Vibrational spectroscopy
Wavelength
Working distance (WD)

### 16.5.2 Review Questions

1. What characteristic separates microscopic evidence from other evidence?
2. What instrument is employed for the collection and first evaluation of small evidence?
3. How is the total magnification of a microscope determined?

4. What is the most important factor in determining the resolving power of a microscope?
5. What are the important factors for the reporting of refractive indices?
6. What are the characteristics that firearms examiners evaluate to match a projectile to a weapon?
7. Explain plane polarized light.
8. What determinations about a glass fracture can be made by macroscopic examination?
9. What are the three major portions of a hair or fur fiber?
10. What is the value of visible microspectrophotometry for fiber comparisons?
11. What information about a paint sample can be obtained by use of infrared microspectrophotometry?
12. What data are obtained from a paint sample by use of SEM/EDS?
13. What fraction or type of mineral is of most value for soil comparison?
14. What is working distance and how does it vary with objective magnification?
15. How could one increase the magnification of a compound light microscope and not change the working distance?
16. What stage of hair growth usually results in the loss of hair?
17. What elements, when found in a spherical particle, are considered necessary to conclude that the particle is characteristic for a gunshot residue?

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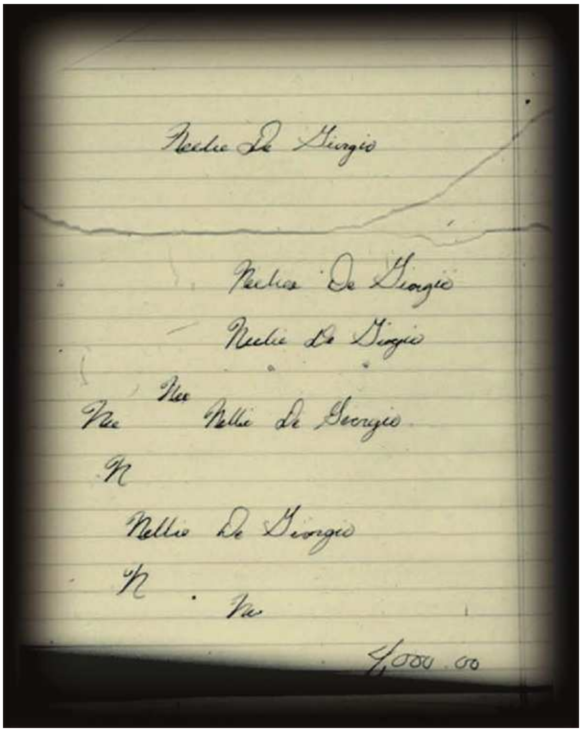
# 17
# Questioned Documents



## Chapter Overview

In the broadest terms, a **document** is any fixed method of communication between one individual and another. A **questioned document (QD)** is one that in its entirety or in part is suspect as to authenticity or origin. Questioned documents include more than checks, wills, and contracts. A typewritten letter, dollar bill, postage stamp, gas station receipt, or concert ticket can be a questioned document.

The field of questioned documents is one of the older disciplines in the forensic sciences, dating back to ancient times. Today, the field of questioned documents is credited to the pioneering work of Albert S. Osborn, who was born in 1858. His publication *Questioned Documents* set forth the basic principles that document examiners still utilize. This book is considered the bible of questioned documents. The significance of the document examiner was brought to the attention of the legal system in the Charles Lindbergh baby kidnapping trial, which became known as the "Trial of the Century." Osborn's testimony was crucial during the Lindbergh trial, as he demonstrated that the ransom note was written by the suspect Richard Hauptmann. In the early 1930s and 1940s, the Federal Bureau of Investigation (FBI) and the U.S. Postal Department, respectively, established their questioned document laboratories. Today many states and county law enforcement agencies employ document examiners.

As with trace evidence, the forensic analysis of questioned documents covers a wide range of evidence and uses a wide variety of forensic tools for its analysis. Handwriting analysis can be considered a type of pattern evidence, and a database has been created to store example patterns of writing. Counterfeiting of currency and, more recently, credit cards requires physical and chemical analysis of inks, paper, and plastics. Advances in printing, personal computers, scanners, and copy machines have changed the nature of QD examination in ways that could not be imagined by Albert S. Osborn. Therefore, like the field of trace evidence analysis, analysis of QDs requires examiners to be skilled in a variety of sciences and even, in some cases, art.

# Chapter 17
# Questioned Documents*

*Howard Seiden and Frank Norwitch*

## Chapter Outline



## 17.1 Functions of a Forensic Document Examiner

Who wrote the threatening letter to the politician? Whose signature is on the dotted line of the contract? Is the endorsement signature on the back of the check genuine? When was this document typed? What does the faded writing say? Is this a genuine or counterfeit document? An individual who is trained in the field of questioned documents is the person who can answer these questions. (For a discussion of career preparation for this field, see Sidebar 17.1.)

* This chapter is based on Chapter 22, "Questioned Documents," by Howard Seiden and Frank Norwitch, as published in the third edition of this text.

### SIDEBAR 17.1. CAREER PREPARATION AND EXPECTATIONS

As with many forensic careers, document examination requires significant on-the-job training and a solid scientific education. Oklahoma State University offers online coursework leading to a graduate certificate in forensic examination of questioned documents (QDs). This coursework was established in cooperation with the American Board of Forensic Document Examiners. This course of study supports programs that prepare document examiner trainees for certification. Other schools offering degrees in forensic science have coursework dealing with the study of questioned documents. Usually a training program consists of a 24-month internship. The trainee works and learns from a senior document examiner and has practical problems to work, literature to read, and research to do. There are lectures, tests, actual casework with the trainee giving reasons for arriving at an opinion, and mock trials. The Federal Bureau of Investigation and Secret Service offer schools in questioned documents that the individual should attend for additional training. Examiners should also continuously avail themselves of the various QD seminars and workshops presented by professional affiliations and law enforcement agencies. Good resources on the web include the American Society of Questioned Document Examiners (http://www.asqde.org/) and the website of the Secret Service (http://www.secretservice.gov/).

A forensic document examination can involve the comparison of handwriting and signatures, typewriters and printing devices, **alterations** and **obliterations** of documents, counterfeiting, photocopy manipulation, rubber-stamp impressions, inks, paper, and much more. The document examiner may be involved in criminal cases involving written threats, anonymous letters, extortion, fraud, identity theft, elderly abuse, white-collar crime, and contract disputes. Many examiners are employed by government agencies. Other examiners in private practice are involved in civil casework, such as medical malpractice and insurance fraud. (See Sidebar 17.2 for a historical note on counterfeiting and the Secret Service.)

### SIDEBAR 17.2. HISTORICAL NOTE: COUNTERFEITING AND THE SECRET SERVICE

Most people associate the U.S. Secret Service with the agents that protect the President and other high-ranking officials, but this is not why the Secret Service was founded; rather, it was organized to combat counterfeiting of currency. Counterfeiting has a history as old as money itself and was treated more seriously in the past, when the death penalty was used to punish counterfeiters. In the United States, counterfeit currency was a weapon exploited by the British to flood the market, making the Continental (the nickname for the dollar issued in the colonies) all but worthless. The Civil War brought on an abundance of counterfeit currency in the United States, particularly in the Confederate states. The first national currency was adopted during the war, in 1862. This act only temporarily slowed counterfeiting. As a result, the U.S. Secret Service was formed in July of 1865 with the mission of stopping it. It was not until 1902, after the assassination of President William McKinley, that the Secret Service was charged with protecting the President.

A document examiner's expertise may be needed for verification of a person's signature on a sign-in sheet to prove or disprove the alibi of an individual who claims to have been at a particular location or present at a certain time. The identification of an individual's writing on checks, credit card invoices, or contracts may reveal those who are involved in fraud. The writing-on-demand notes or threatening letters can serve to identify the individual. From the examiner's analysis, an opinion is rendered in the form of a report that the attorney can use to assist his or her case. If the case goes to trial, the document examiner should be prepared to state his or her opinion clearly to the judge or jury and demonstrate to the court why such an opinion was formed. Such a demonstration usually takes the form of an enlarged photograph of the known and questioned material. The examiner can then point out significant similarities or dissimilarities and discuss their merits before the court.

## 17.2 Handwriting Comparison

Think back to your early days in school when you spent a period learning how to write. There in class, above the blackboard, were charts demonstrating a particular writing style. Instruction was given on the correct printing of letters and later on how to write cursively. Depending on your geographic location, you were taught one of various **copybook** styles of penmanship, such as the Palmer and Zaner–Bloser methods. During this early learning period, attention was focused on how to write the letters of the alphabet correctly. As the individual matures, his or her writing tends to deviate from the copybook style of writing, and the emphasis shifts to what is being written rather than how the letters are formed. Neuromuscular coordination and visual perception differ from one individual to another. Individuals may incorporate shortcuts from the copybook style or add an extra flair to their writing, perhaps because they saw it in someone else's writing. By the late teenage years, a person's writing has matured to the point where his or her writing style is unique. Handwriting is an acquired skill that becomes ingrained; it is habitual as well as individualized. This individualization is a basic principle in document examinations.

### 17.2.1 Collection of Writing Standards

Before an examination can be made, known standard writing must be submitted for comparison purposes. Usually the investigator submits standards for comparison. If the investigator does not submit proper standards, then an examination may be limited in scope or may not occur. It is crucial for the investigator and document examiner to have a good working liaison. When submitting written standards, one should realize that like must be compared to like. For example, if the questioned material is printed, the known standards must be printed. If the questioned document is written cursively, it must be compared to cursive writing. If the writing is in pencil, the standards should be written in pencil. A general rule is to duplicate as much as possible the same conditions that occurred when the questioned material was written. Items such as writing instrument, writing position (if known), and type of paper (ruled or not) may be important conditions of the writing act.

Two classes of writing standards are utilized for comparison purposes. These are **non-request writing**, also known as spontaneous or un-dictated writing, and **requested writing** or dictated **exemplars**. Both types of standards have benefits and disadvantages. The non-request or un-dictated writing—material written by the individual during the everyday course of business—is likely to reveal the normal writing habits of the individual. No circumstances call attention to or provide undue emphasis to the act of writing. The writer, unaware that the writing will be used as a standard for comparison, is not likely to alter his or her handwriting for the purpose of disguise. The disadvantage is having the non-request written material authenticated for court, as obtaining enough comparable letters and words can be difficult.

Requested exemplars are standards written at the request, and usually in the presence, of the investigator or examiner. Their advantage is that they provide writing that is comparable to the questioned material, and authentication is easily accomplished. The inherent problem with requested standards is that they call attention to the writing process. This may inhibit the writer because of nervousness or may allow the writer to attempt to distort his or her writing for the purpose of disguise. From the examiner's perspective, a combination of both requested and non-request writing standards serve as the best material for comparison to the questioned document. The addition of non-request standards serves as a check against the individual who may attempt some form of disguise.

Normal course-of-business writing standards can be obtained for handwriting examination from

- Applications (credit, employment, insurance, loan, rental)
- Bank records (deposit slips, cancelled checks, safe deposit record, signature cards)
- Birth certificates
- Business contracts and agreements
- Employment records
- Letters of correspondence
- Real estate (contracts, listings, warranty deeds)
- Receipts (credit card, cash, delivery)
- Registers (attendance, motel, visitor)
- School records
- Tax returns
- Time sheets
- Wills

### *17.2.2 Process of Comparison*

A document examiner compares questioned handwriting or signatures side by side with the known standards. Handwriting attributes are examined both visually and microscopically. Everyone who looks at writing and signatures notices the most conspicuous features first, such as the **slant** of the writing and how the letters are formed. An examiner will look beyond the obvious features and study the subtle, inconspicuous aspects of the questioned signature or writing. By applying basic rules in document analysis, combined with experience observing thousands of letter formations and words, an expert examiner is able to determine whether or not writing is genuine.

A good analogy to handwriting identification that is taught to beginners is suppose that you have been given a general description of a person. He is a 30-year-old male with dark hair and eyes; he weighs 160 pounds and is 6 feet tall, and he has a scar on his forehead, tattoos on his arms, and a limp. You must find this individual among a group of passengers who are coming off a plane at the airport. The first five characteristics are common; many men fit that general description. With the addition of the next three uncommon characteristics, the field narrows significantly. With all the traits combined, when you see this individual and your brain has processed the description, you will recognize him in the crowd. If the individual differed in weight by a few pounds or in age by a few years, that would not be significant. The general description could be off slightly without changing the identification. However, if one of the last three traits was missing, that would be significant, and you may not have the right individual. The analogy applies to handwriting. Some writing features are common, and some handwriting characteristics are considered uncommon or even rare. The common features are referred to as *class characteristics*, and we have discussed these before in the context of pattern evidence.

Class characteristics are writing attributes observed in a group of writers that are probably derived from a penmanship system they learned. The uncommon handwritten characteristics, known as *individual characteristics*, are considered distinctive, personal, or peculiar to the handwriting of one person. An experienced document examiner is able to recognize class characteristics and avoid identifying an individual's writing solely on the basis of these common handwriting features. If the writing is naturally executed, and a combination of similarities between the questioned material and known standards is significant and individual, the examiner renders an opinion that the questioned and known materials were written by the same individual. If the questioned writing or signature contains a combination of significant dissimilarities or indications of forgery, the examiner may proffer an opinion of not genuine. In doing a comparison, an examiner studies characteristics, such as how letters are constructed, how they are connected, the **beginning** and **ending strokes** of letters, the relative **height ratio** of letters, the spacing between letters and words, the skill level, speed, size, and **shading**.

To account for variation in a person's writing, an examiner needs an adequate number of writing or signature standards to compare. Writing variation represents the alternative forms of a single handwritten characteristic found in a person's writing. One principle in document examination is that no two individuals write exactly alike, and another principle is that no one person writes exactly the same way twice. An individual has a repetitive range to his or her writing. Not every letter will be exactly the same or every beginning or **terminal stroke** of a letter the same. Every time a person writes, the pen or pencil may start at a slightly different speed or point on the paper. However, a basic pattern or habitual style is still inherent within a person's writing. An examiner looks for this pattern in the standards. He or she can then determine whether the questioned writing is within the range of a person's variation.

An illustration of this concept is the "th" height ratio in the word "the." Is the "t" higher than the "h," lower than the "h," or the same height? An examiner would study all the words that a person writes that contain a "th." Let us suppose that one individual habitually writes the "t" higher than the "h." At times, the "t" may be much higher than the "h" and sometimes just a little bit higher. Any slight change with respect to the height of the "t" would be considered variation within his or her writing, as long as the basic habit of making the beginning "t" higher than the "h" remains. A study of 200 individuals by Muehlberger et al. (1977) showed that 5.5% made the "t" taller than the "h," 78% made the "t" shorter than the "h," 15% showed no pattern, and 1.5% made the "t" even with the "h."

### *17.2.3 Types of Fraudulent Writing*

Types of fraudulent writing include **freehand simulations**, **tracings**, and normal hand forgeries. A freehand simulation is an attempt to draw the signature or writing of another person (Figures 17.1 and 17.2), usually when working with a model signature. This type of forgery requires that the individual maintain the same speed as the original writing and imitate the correct letter formations, height ratio, and **pen pressure** at the same time. This presents the forger with quite a challenge. If his or her attention is directed at maintaining the speed of the writing, as in a stylized signature, then less concentration can be focused on replication of the correct letter formations and **connecting strokes**, and the chances are greater that these characteristics will be wrong. If the forger attempts to make the letters and connecting strokes correct, then he or she will pay less attention to the speed of the signature. The **line quality** will suffer—the signature will display an awkward uneven line that appears hesitant and drawn. Adding to this challenge, the forger must continuously suppress his or her own writing habits so they will not be revealed in the simulation. Upon closer microscopic examination, evidence may be observed of the forger's **patching** or **retouching** of the written line to make it appear closer to the genuine signature. Additional characteristics of **blunt starts** and stops, as well as **pen lifts**, may also be revealed. A competent examiner should have little problem in discerning a freehand simulation.

Tracing, another common type of simulation, involves using an original signature or writing as a guide to produce a fraudulent document. Indications of a tracing include the presence of guidelines around the questioned signature, such as graphite from a pencil or remnants of a line from carbon paper. Indented impressions around the questioned writing may signify that an impression of the original signature was made with a pointed object and then a pen was used to go over the impression. A more direct approach is to take the original signature or writing, place the fraudulent document over it, and trace it. A tracing will normally reveal poor line quality. Instead of the written line appearing smooth and free flowing, it will be uneven and wavy and appear to have been drawn slowly. The final product will not reveal the shading differences in a freely and naturally executed signature that is written with a fair amount of speed.

In a **normal hand forgery**, the individual does not attempt to copy the victim's signature or writing. The forger either writes the name in his or her own writing style or tries to distort it. **Disguised writing** is another form of fraudulent writing. The individual attempts to alter his or her writing to be able to deny later that he or she was the author. Methods of disguise vary from altering the slant of writing to changing the size of writing. Some individuals alternate between upper case and lower case letters or printed and cursive forms of letters. Others add additional strokes to letters. The more a person writes, the more difficult it is to suppress habitual writing characteristics. Because the act of writing is an acquired skill that has become habitual, a person will find it challenging to maintain an effective disguise. The smaller, inconspicuous writing characteristics of the individual are revealed the more a person writes. It is difficult to write effectively and concentrate at the same time on altering learned handwriting habits.

### *17.2.4 Factors That Can Affect Handwriting*

Many factors can affect handwriting. For a more detailed overview, the reader should consult the chapter references. The health of the writer is a consideration. Various disorders can produce muscular weakness that prevents proper writing

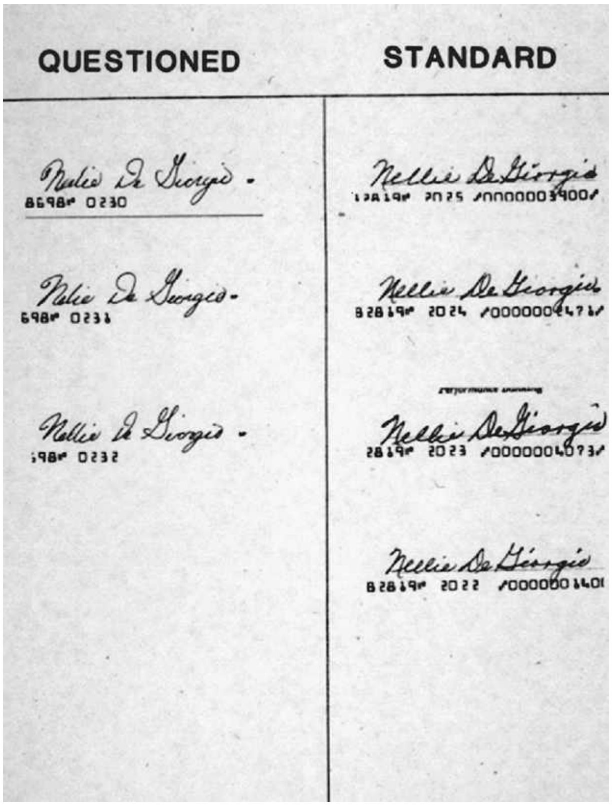



***Figure 17.1*** A comparison chart used in court to demonstrate a freehand simulation.

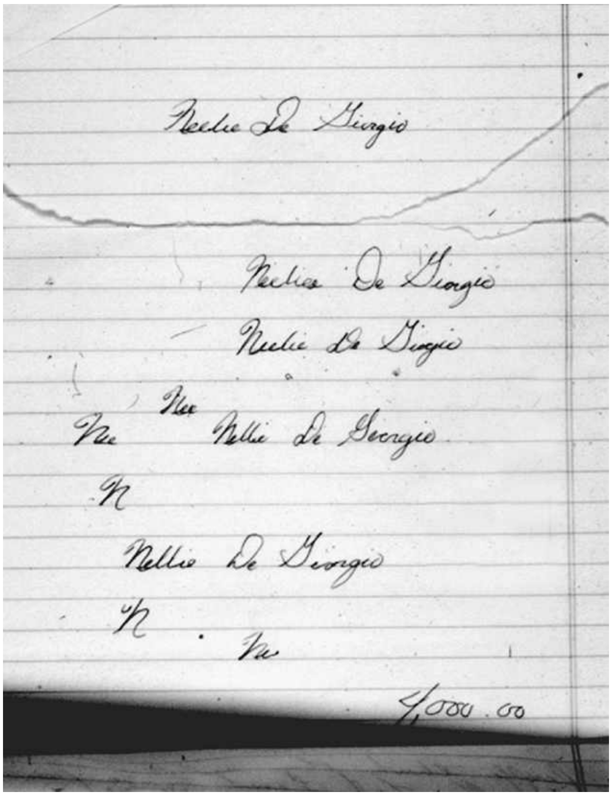


***Figure 17.2*** A practice sheet revealing the forger's attempt to write the victim's signature.

control or reduces the ability to hold a writing instrument correctly. An individual who normally has legible handwriting may suddenly be overtaken by arthritis; the resulting change in handwriting may be abrupt and cause the writing to become unrecognizable as that individual's writing. A stroke may change a person's handwriting severely; the resulting product may be illegible and totally different from the writing before the stroke. Parkinson's, usually a disease of the elderly, can also affect the middle-aged. It causes the destruction of brain cells, resulting in muscular tremor and weakness that have a noticeable effect on handwriting; the hand tremor of Parkinson's results in a wavering written line. Essential tremor, another neurological condition commonly observed in the elderly, causes the arm to shake and leads to difficulty in handwriting.

As individuals age, their handwriting may undergo noticeable deterioration. A loss of pen control and smoothness of the line can be observed. Senility can cause changes in handwriting. It is important for the examiner to receive written standards that are contemporaneous with the time the questioned document was written. Consider a will that was written 5 years ago and bears a questioned signature. This signature is naturally executed and stylized. Signatures of the deceased are provided that date back to only a year ago, but these standard signatures exhibit a loss of pen control and deterioration in letter formations. A likely explanation is that the individual suffered some recent debilitating condition that affected his or her writing capability. In order to facilitate an examination, the examiner should request signature specimens that were written at about the same time as the disputed signature.

The effect of alcohol on writing has been studied extensively. With increasing blood alcohol levels, the quality of writing starts to degrade. As muscular coordination becomes poorer, the writing becomes less legible and the size of the writing may increase. The writer becomes careless and introduces errors. These effects may not be the same for each individual.

## 17.3 Alteration, Obliteration, and Ink Differentiation

Often a document examiner discovers and deciphers an alteration to or obliteration of a document, or determines an ink differentiation. The obvious and discernible evidence of a second writing instrument may well prove that an addition has been made after the fact. Occasionally, an examination of what appears to be a rather straightforward medical record reveals a trail of deception and attempts to mask evidence of wrongdoing. In addition to a naked-eye or low-magnification visual examination of the questioned material, an examination may also incorporate the use of selective color filters or color filter combinations. This could be the method of choice, for instance, in the examination of obscured, blood-stained documents. Although at times this visual examination reveals evidence leading to a definitive opinion, usually a more thorough examination is necessary. Viewing by microscope may reveal subtle differences, such as a slight change in shading or hue, within the questioned material. Secondary lines, indicative of alteration when present, are usually discovered during this process. More in-depth examinations of the questioned document using selective portions of the electromagnetic spectrum can be accomplished either photographically or by a process generically known as **video spectral comparison (VSC)** (Figures 17.3 and 17.4). Inks can also be characterized using thin-layer chromatography (TLC) (see Chapter 10, Figure 10.6).


***Figure 17.3*** Video spectral comparator (VSC) revealing security features using ultraviolet light.


***Figure 17.4*** Infrared filters used to discriminate inks.

## *17.3.1 Video Spectral Comparison*

As we discussed in the last chapter, colors as perceived by human vision represent one small region across the electromagnetic spectrum. Trace analysts exploit interactions of evidence with other types of energy, most commonly infrared (IR) and to a lesser extent ultraviolet (UV). Questioned document examiners also exploit these regions during the analysis of paper and ink. Although we are not able to see in the infrared or ultraviolet regions of the light spectrum with the naked eye, we can use instrumentation to convert those wavelengths into visible images when examining a questioned document. Different inks that appear similar to our unaided eyes may react quite differently when viewed under ultraviolet light or with the use of infrared imaging techniques.

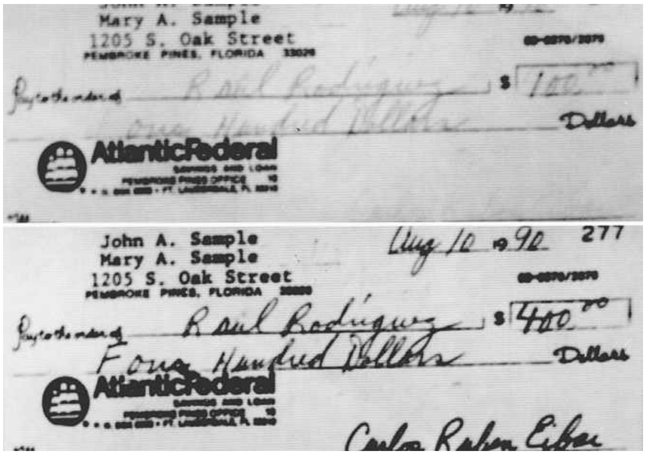



***Figure 17.5*** An example of check alteration using VSC infrared reflectance. The bottom portion of the photograph reveals the altered check in the amount of $400. The top part of photograph displays the original entries.

When examined using infrared, an ink can be observed to luminesce or glow, be transparent, or appear unchanged, depending upon its chemical properties (Figure 17.5). The infrared examination may use specialized light filters and films for photographic imaging or equipment specifically designed for infrared imaging. This process is referred to as *video spectral comparison*, and the equipment is usually referred to as a *video spectral comparator*. In addition to the VSC being used on ink examinations, this instrument is being routinely employed to detect forgeries in passports, visas, identification cards, immigration documents, etc. Many security documents utilize luminescent features, such as holograms and watermarks. The VSC can easily check for authenticity. Additional features include an embedded information decoder. This is where personal information is invisible on passports.

### *17.3.2 Thin-Layer Chromatography*

Another useful analysis that is occasionally employed is thin-layer chromatography (TLC), a technique discussed in Chapter 10. The TLC process is usually used for ink comparisons rather than obliterations. When used in conjunction with the other methods described above, TLC affords the examiner the most frequent opportunity to issue conclusive opinions concerning two or more inks on one document. Small, almost microscopic "punches" of the ink are taken from a portion of the written line that is least likely to play a prominent part in any subsequent handwriting examination. Places where the moving pen changed direction or where ink lines intersect are avoided. Punches are made by using a blunted hypodermic needle, preferably one with a small diameter such as those used for insulin injections. These work well and do little damage to the document. These punches (some three or four or more) containing portions of the suspect ink are placed into a small test tube, and the ink is separated from the paper portion of the punch by the introduction of a solvent such as pyridine. The resultant ink and solvent solution is spotted onto paper or glass TLC plates. The plate is placed in the solvent and allowed to develop. Portions of the ink spot separate into bands of color and migrate upward along with the solvent. Each of these (usually three or four) bands reaches a stopping place on the strip. A comparison of bands created by different suspect ink areas may at times allow for conclusive opinions of difference; however, even if the TLC bands created from different ink spottings appear in the same pattern, a conclusive opinion that both the questioned inks are from a common source (or writing instrument) is not possible. Each ink manufacturer fills thousands of writing instruments, sometimes for different pen distributors, with ink of the same formulation. These formulations are changed infrequently over the years. The best that can be said is that the inks appear consistent and could have come from a common source. Although most TLC processes have the best results when traditional ballpoint pen inks are involved, other solvents can be employed to use TLC for other inks, such as those found in rollerball or plastic tip pens. A simple example of a TLC analysis of inks is shown in Chapter 10, Figure 10.6.

## 17.4 Indented Writing

**Indented writing** or second-page writing is the impression from the writing instrument captured on the second sheet of paper below the one that contains the original writing. This most often manifests itself on pads of paper. Indented writing can be a source of identification in anonymous note cases and is an invaluable investigative procedure when medical records are suspected of containing alterations. Often, a writing addition to a record or file can be revealed by an impression that has been transferred to the page below. Indented writing on subsequent pages may not be in agreement with what appears on the surface of the document. Writing found to be out of position, missing, or added after the fact can often be demonstrated by recovering and preserving indented writing from other pages. Mystery novels and television and movie plots sometimes depict recovery of indented writing as part of a clue. The method they usually show for reading indented writing from suspect pages is to rub a soft lead pencil or carbon paper over the surface of the document, causing the indentations to be highlighted in relief. Although entertaining, this technique is one way to destroy what might be valuable evidence and should serve as a warning against amateur examinations. Indented writing is normally recovered either photographically using oblique (glancing) light or by use of **electrostatic detection apparatus** (**ESDA**) (Figure 17.6).

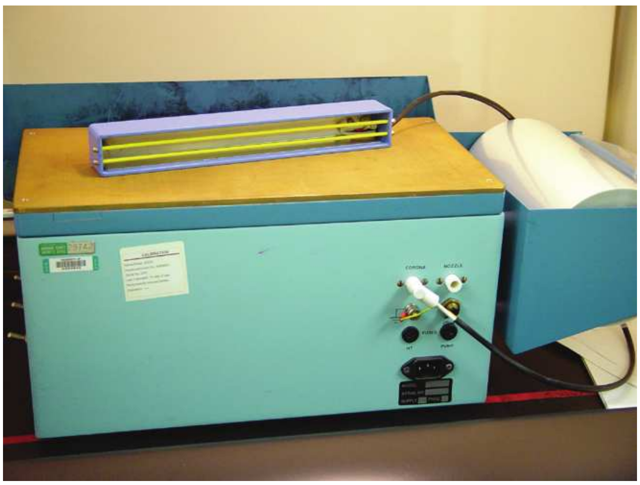


***Figure 17.6*** The ESDA and the electrically charged wand.

### *17.4.1 Photography*

Until recently, the forensic document examiner applied **oblique lighting** (or glancing light) to the furrows of indented writing. Photography was then employed to preserve the shadowed indentation. A combination of multiple exposures taken while moving the light source fills in the available indentations with shadow and effectively reproduces the indented writing. While such techniques are often acceptable, they lack the ability to recover invisible microscopic indentations (those occurring three or four pages down) and have an inherently lengthy processing time.

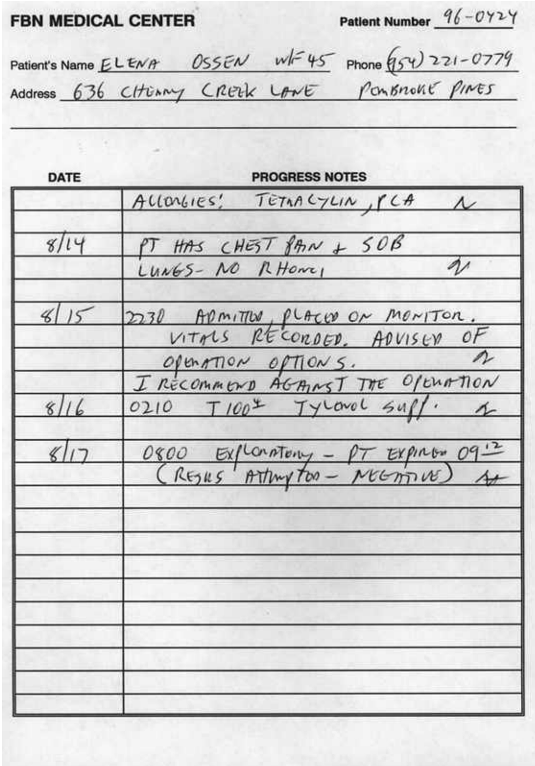
### *17.4.2 Electrostatic Detection*

The modern well-equipped forensic laboratory employs electrostatic detection apparatus (ESDA) to recover indented writing. With ESDA, indented writing can be recovered three, four, or even more pages below the original writing. A preliminary examination eliminates documents or cases in which the material to be examined is unsuitable for the detection and recovery of indented writing by electrostatic detection. Documents that have been previously processed for latent fingerprints with ninhydrin or that have been saturated with fluids normally fall into this classification. Thick cardboard mediums are usually incompatible with ESDA. The document to be processed may need to be humidified slightly if it has been kept in, or had as its source, an arid environment, such as an interior page from a pad of paper. This helps the **electrostatic charge** to develop. In more humid climates, several hours exposure to normal room air serves the same purpose for most documents.

The page suspected of bearing indentations is covered with a cellophane (Mylar®) material, which is then pulled into firm contact with the paper by a vacuum drawn through a porous bronze plate. This fastens the document and cellophane covering to the plate. The cellophane covering prevents damage to the original document. The examiner then subjects the document and cellophane to a repeated high-voltage static charge by waving an electrically charged wand over the surface of the document.

This results in a variably charged surface, with the heavier static charge remaining within any impressions, even those that are microscopic in depth. Using microscopically sized glass beads as the carrier, black toner (similar to that used in dry-process photocopy machines) is then cascaded over the cellophane surface, or it can be applied by “misting,” where the toner is sprayed over the paper within a chamber placed over the questioned document. The toner is strongly attracted to static electricity and is retained on the cellophane surface in accordance with the amount of residual static charge present at any given surface point. The areas of the document containing the higher static electric charge retain greater portions of the black toner, resulting in a deposit of toner aligned with the indentations in the paper.

The developed indentations may be photographed. They are preserved by placing an adhesive-backed clear plastic sheet over the cellophane while it is still being held in place by the vacuum of the ESDA (Figures 17.7 and 17.8). The advantages of electrostatic detection are twofold. First, ESDA is nondestructive. The indentations are revealed on the protective cellophane surface and are fixed by applying pressure-sensitive adhesive plastic over the cellophane. The original document remains unharmed throughout the process. Second, ESDA is extremely sensitive, allowing indentations that are not revealed by any other method to be readily observed and recovered. If the recovered indented writing is of a high enough quality, the handwriting in the indentations, used in comparison with standard material, may even serve as a method to associate somebody with the questioned document.



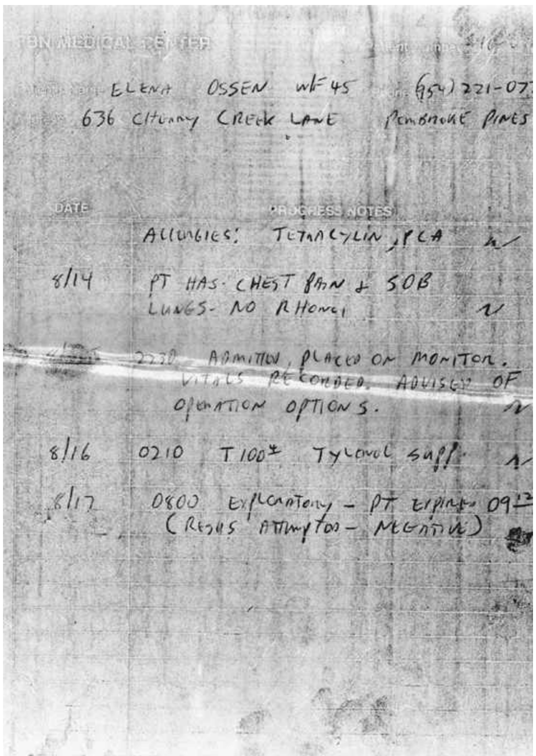
FBN MEDICAL CENTER Patient Number 96-0424

Patient's Name ELENA OSSEN wF 45 Phone (954) 221-0779

Address 636 CHERRY CREEK LANE PEMBROKE PINES

| DATE | PROGRESS NOTES |
|---|---|
| | ALLERGIES: TETRACYCLIN, PCA |
| 8/14 | PT HAS CHEST PAIN + SOB |
| | LUNGS- NO RHONCI |
| 8/15 | 2230 ADMITTED, PLACED ON MONITOR. |
| | VITALS RECORDED. ADVISED OF |
| | OPERATION OPTIONS. |
| | I RECOMMEND AGAINST THE OPERATION |
| 8/16 | 0210 T 100⁴ TYLENOL SUPP. |
| 8/17 | 0800 EXPLORATORY – PT EXPIRED 09:12 |
| | (RESUS ATTEMPTED – NEGATIVE) |

*Figure 17.7* Original page of a questioned document medical record suspected of being altered. (Note that there are no initials after the questioned entry.)



FBN MEDICAL CENTER

ELENA OSSEN wF 45 (954) 221-07

636 CHERRY CREEK LANE PEMBROKE PINES

| DATE | PROGRESS NOTES |
|---|---|
| | ALLERGIES: TETRACYCLIN, PCA |
| 8/14 | PT HAS CHEST PAIN + SOB |
| | LUNGS- NO RHONCI |
| | 2230 ADMITTED, PLACED ON MONITOR. |
| | VITALS RECORDED. ADVISED OF |
| | OPERATION OPTIONS. |
| 8/16 | 0210 T 100⁴ TYLENOL SUPP. |
| 8/17 | 0800 EXPLORATORY – PT EXPIRED 09:12 |
| | (RESUS ATTEMPTED – NEGATIVE) |

*Figure 17.8* The resultant ESDA impressions raised from the next page down in the medical record file reveals a missing line, making it obvious that this entry was written subsequent to the original entries.

## 17.5 Photocopy and Photocopier Examination

### *17.5.1 Photocopier Identification*

Most modern-day photocopying machines operate in a more or less similar fashion. The image of the document to be copied is captured by a camera lens and transferred to a cylindrical drum usually coated with a light-sensitive substance, such as selenium. This drum has been charged with a static electric charge, which dissipates when exposed to light. The image of the document transferred to the drum is made of light and dark areas that create similar or corresponding areas of more or less static electric charge on the drum. The drum is then bathed with toner, which is in either a dry or wet form depending on the specific machine. Toner has an inherent affinity for static electricity and clings to those areas of the drum in quantities proportional to the electrostatic charge. The toner in turn is transferred to a piece of paper that is then subjected to a fixing process, usually in the form of heat that fuses and attaches the toner to the paper. Paper is pulled through the photocopying machine by **grabbers**. Marks made by the grabbers are transferred to the paper. These may be small depressions at the edge of the paper, areas of toner, or toner-less spots on the finished photocopied document.

A machine may leave on the photocopy characteristics that are specific to a particular make and model within a manufacturer's line. Such characteristics can include grabber marks, paper edge depressions, designs incorporated into specialized paper for specific machines, paper type, and toner type. The examiner notes characteristics and then searches through reference files. At times, highly definitive opinions as to make and model are possible. (If the questioned photocopy is a second, third, or more generation removed from the original document, and if two or more different photocopy machines have been used in its lineage, the examination is more difficult and the likelihood of a definitive opinion is greatly decreased.) The database of reference material must be updated continually because of the short life of most photocopier models and almost daily introduction of new models and technology.

### *17.5.2 Photocopy Examination*

Questioned photocopies can be examined visually for individual characteristic **trash marks** that may be made because of dirt, scratches, and other extraneous marks on the surfaces of the drum, cover, glass plate, or camera lens of a photocopy machine (Figure 17.9). A comparison of these marks on the questioned document with those marks made by a specific machine can identify or eliminate that particular machine as the source of the document. Similarly, a side-by-side comparison of two or more questioned photocopies may reveal if they are the product of a common photocopy machine. As in photocopier identification, multiple generations of copies and the involvement of more than one photocopy machine severely limit the conclusiveness of the resulting opinions.

### *17.5.3 Photocopy Forgery*

When the document examiner examines a photocopy to determine the genuineness of the original signature as represented by the photocopy, the examination must take into account the possibility that a genuine signature was affixed to a

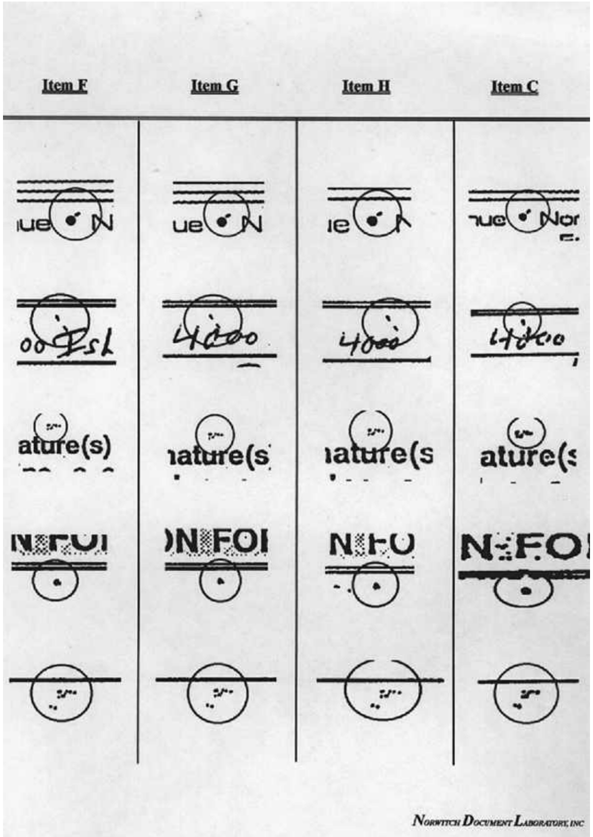



*Figure 17.9* A demonstration chart showing the same photocopier "trash" marks on different documents. This proves these four documents were copied on the same photocopier.

fraudulent document and the composite, or paste-up, photocopied. This may result in what would appear to be a photocopy of an original document bearing a genuine signature. The same may be true of any other portion of a photocopy. Photocopies can be prepared from a composite of parts of two or more documents which, when copied, can appear to be a reproduction of a single document. The resultant copy, made from composites, may or may not display characteristics indicative of its production from two or more document sources.

Indications of spuriousness include misaligned typing; different fonts and font sizes; misaligned preprinted matter; incorrect vertical, horizontal, and margin spacing; "shadowing" in the joined areas; disproportionate area sizes; different preprinted material and ink densities; and missing portions of writing or printing (e.g., covered by the paste-up, too closely trimmed, masked by an opaque fluid). The trash marks surrounding the signature may be of greater or lesser quantity than those on the remainder of the document. This is especially true if either the model signature or document to be used in the paste-up was itself a photocopy. The best indication of a possibly fraudulent photocopy is a claim that the original document has "disappeared" or has been "misplaced."

Even when none of these indications of photocopy forgery is present, the prudent document examiner who issues an opinion about the authenticity of a signature or an entire disputed document, when the submitted evidence is a photocopy, will qualify his or her opinion. The qualifier is a statement that the opinion is predicated upon the questioned document being a true and accurate reproduction of the original document. Many examiners go even further by including a statement in their

**SIDEBAR 17.3. HISTORICAL NOTE: THE LINDBERGH KIDNAPPING**

The examination of questioned documents was well established in Europe and the United States by the 1930s, but it took a famous case to bring it to the public's attention. Charles A. Lindbergh became a national and international hero in 1927 after flying the Atlantic alone in the *Spirit of St. Louis*. He later married Anne Morrow. Their first child, a son named Charles, Jr., was 20 months old when he was kidnapped at around 9:30 p.m. on March 1, 1932. A ransom note, one of 14 that would be sent by the kidnapper, demanded $50,000 in ransom for the boy's safe return. Mailed notes all had postmarks from the New York City area. The investigation by the New Jersey State Police was headed by Colonel Norman Schwartzkopf, father of the general who would later lead coalition forces to victory in the 1991 Gulf War. Eventually, a ransom of $50,000 was paid, the majority of it in gold certificates, which were used as currency at the time. Serial numbers of the bills were recorded before the money was delivered. Sadly, the body of the child was found one month later.

report of findings that addresses the accuracy of opinions involving photocopies upon viewing the original document prior to any court testimony. Photocopies that display prohibitively poor quality may be precluded from examination, but those displaying adequate line quality are deserving of some degree of qualified opinion. (See Sidebar 17.3 for a historical note regarding the Lindbergh baby kidnapping.)

## 17.6 Paper and Watermark Examination

Paper examinations usually are necessary when there is some question as to whether or not one or more pages have been added to a multipage document or if a document was created at the time that it was purported to have been created. A last will may be one such document. There may be a suspicion that one or more pages have been added or replaced subsequent to the original execution of the document. The simple examination of the staple and staple hole can sometimes shed light on the authenticity of the document. A will having only one staple in the top corner may have evidence of previous staples (holes) in subsequent pages. This would indicate that one or more pages have been added or replaced and the will restapled.

Paper is commonly made of wood or cotton materials. During its production, various **sizings**, fillers, and coatings are added. Sizings, such as rosin, enable the paper to resist ink penetration. Fillers, such as clay, calcium carbonate, and titanium dioxide, improve the surface and color of the paper. Various coatings are added to the paper to improve its appearance and printing properties. These additives vary from one paper type or paper manufacturer to another. Chemical testing can determine which of these materials is present, and even the type of wood that was used in the paper's manufacture. A comparison of the results of such testing can associate or dissociate a questioned page with a known standard. Unfortunately, these processes are destructive in nature and require sampling of both the questioned and standard paper. This is most often not convenient or allowed by the courts. Many other properties of the paper, however, can be investigated and compared.

### *17.6.1 Paper Size and Thickness*

Although there are standard sizes for paper, such as letter (8.5 × 11 in.) or legal (8.5 × 14 in.), very small differences in lengths and widths exist among different manufacturers' products and even among different papers in a specific manufacturer's paper line, or even between different runs of the same paper. While these small differences can be measured, the simple process of stacking the questioned and standard paper readily displays differences in size. Minute differences in paper thickness can also be detectable. This determination requires instrumentation with a paper **micrometer**. Most micrometers display differences in thousandths of an inch.

### *17.6.2 Paper Opacity, Color, and Brightness*

Paper opacity, color, and brightness are directly related to the chemical additives that were put into the paper during its manufacture. Differences between two papers in these areas may, at times, be easily observed with the naked eye. When held up to a light source, one paper may transmit more light than another. Obvious differences in color or shading between papers can likewise be an unaided observation. Often two papers with brightness that appears similar to the unaided eye display differences when subjected to a short-wave or long-wave UV light source. Whereas one paper may remain dull in appearance, the other may almost glow.

### *17.6.3 Watermarks*

Some papers, when held up to the light, display an area of translucent design—the **watermark**—incorporated into the paper by one of several different methods during the paper manufacturing process. These designs contain clues to the paper manufacturer, the entity for whom the paper was produced, and first date of that paper's production. For example, a questioned document that purports to have been executed in 1975 may contain a watermark that, after research, proves that the paper was not made until 1983.

## Chapter Summary

As we have seen, questioned document and trace evidence analysis are similar in that both utilize a range of analytical techniques including chemical and physical methods. The analysis of handwriting is a form of pattern evidence analysis and involves the identification of class and individual characteristics. QD examinations may also call upon chemical and instrumental analyses, including the evaluation of color and study of materials using infrared and ultraviolet spectroscopic techniques. Raman spectroscopy, described briefly in the last chapter, is becoming valuable for ink analysis, and thin-layer chromatography, which we introduced during a description of drug analysis, is a key tool for characterizing and comparing inks.

## 17.7 Review Material: Key Concepts and Questions

### 17.7.1 Key Terms and Concepts

Alterations
Beginning stroke
Blunt starts
Connecting strokes
Copybook
Disguised writing
Document
Electrostatic charge
Electrostatic detection apparatus (ESDA)
Ending stroke
Exemplars
Freehand simulations
Grabbers
Height ratio
Indented writing
Line quality
Micrometer
Non-request writing
Normal hand forgery
Oblique lighting
Obliterations
Patching
Pen lifts
Pen pressure
Questioned document (QD)
Requested writing
Retouching
Shading
Sizings
Slant
Terminal stroke
Tracings
Trash marks
Video spectral comparison (VSC)
Watermark

### 17.7.2 Review Questions

1. Is it possible for a document examiner to tell the personality of an individual from his or her handwriting?
2. Can you determine the sex and age of the writer from his or her handwriting?
3. What is the difference between requested handwriting standards and non-requested standards?
4. Explain the meaning of the term "class characteristics" in relation to handwriting.
5. Can a document examiner identify all types of writing?
6. Name one of the methods of ink differentiation for similar appearing inks.
7. Name one of the methods for the recovery of indented writing.
8. What is a photocopy trash mark and how does it occur?
9. What instrumentation is used to test paper thickness?

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# Section VII Summary

The analysis of trace evidence focuses on microscopy and microscopy coupled to instrumentation that we first discussed in Section 5, Forensic Chemistry. Questioned document analysis also relies on chemical instrumentation and physical measurements as well as pattern matching. Trace analysts use pattern matching as well, and by now you should recognize that pattern matching is fundamental to forensic science. Questioned documents and trace evidence are among the most diverse disciplines within forensic science because, depending on the type of evidence, any number of techniques, procedures, or instrumentation may be needed and used. Both are excellent examples of cross-cutting forensic disciplines.

## Integrative Questions

1. Explain how a trace evidence examiner would approach the analysis of paper used to write a ransom note. What would a QD examiner do? Discuss the similarities and differences in these two approaches.
2. List and briefly describe all the ways we have seen thin layer chromatography used in forensic analysis. What makes it so versatile? What are its limitations?
3. List some other forensic disciplines that might or do make use microscopy.
4. Locard formed one of the first forensic science laboratories, reportedly with two types of instruments—microscopes and spectrometers. Comment on this compared to modern forensic laboratories.

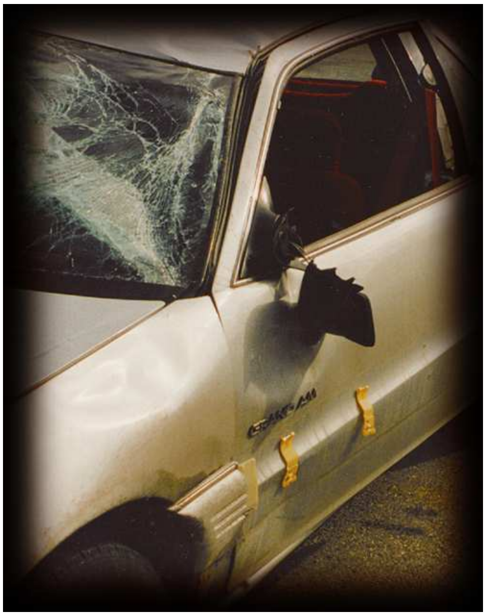
# SECTION VIII

# Engineering and Computing

## Section Overview

Not all forensic disciplines are practiced in a laboratory by someone trained in a traditional science such as we have seen so far. These last two sections will provide an introduction to a few such forensic disciplines. In this section, we will focus on forensic engineering and forensic computing. The latter is one of the, if not the newest, forensic disciplines that evolved alongside of computers. Although the first "computers" in the modern sense were built half a century or more ago, forensic computing coalesced in the 1990s as computers became ubiquitous. Forensic engineering as a practice is much older, but is also a recently recognized forensic discipline. Forensic engineers work to understand accidents and failures, whether they involve cars, trains, bridges, or buildings.

# 18
# Forensic Engineering



## Chapter Overview

Our next two chapters will examine topics that you might not have thought of as being "forensic" but both are becoming central to many forensic and law enforcement investigations. One way to think about forensic engineering is the application of engineering and physics to legal matters; sometimes you will hear the term "forensic physics." In this chapter, we will focus on two aspects of forensic engineering: vehicular accidents and structural collapses, the latter which came to the public's attention as a result of the collapse of the World Trade Center's Twin Towers on September 11, 2001.

# Chapter 18
# Forensic Engineering*

*Randall K. Noon*

## Chapter Outline



## 18.1 Forensic Physics

Fundamentally, the study of collisions, be it between two cars or an airplane with a building, is based on a study of the energy involved and the consequences of this energy being moved and changed. You may recall the first and second laws of thermodynamics, which can be paraphrased as follows:

1. Energy cannot be created or destroyed; it can only be converted from one form into another. In other words, energy is conserved.
2. When energy is converted, the process is never 100% efficient. Some is always lost to other forms, most often heat.

* This chapter is based on Chapter 24, "Structural Failures," and Chapter 26, "Vehicular Accident Reconstruction," both by Randall K. Noon, as published in the third edition of this text.

**SIDEBAR 18.1. CAREER PREPARATION AND EXPECTATIONS**

As of this writing, there are no undergraduate degrees offered specifically in forensic engineering. The National Academy of Forensic Engineers (http://www.nafe.org/) has recommended a curriculum for forensic engineering training at the graduate level, but no such programs have yet been developed. The typical career path is a degree in engineering (master's or doctorate degree) coupled to training or apprenticeship with a practicing forensic engineer. Forensic engineers are usually employed as consultants rather than by forensic laboratories. An interesting recent article on the topic is by D.O. Prevatt, "On the Job Versus Graduate School Training of Forensic Engineers: An Instructor and Professional Engineer's View," *Journal of Performance of Constructed Facilities*, 24(1), 78–86, 2010.

In Chapter 14, for example, we discussed firearms evidence. Think about how a gun works from the perspective of energy: There is chemical energy (CE) stored in the propellant that fills the cartridge. When the propellant is ignited, the chemical energy is released, creating hot expanding gases that force the bullet forward. This is an example of the conversion of chemical energy (propellant) to kinetic energy (movement of the bullet), but not all of the chemical energy is converted into kinetic energy. Some is lost as heat (the barrel gets hot), light (muzzle flash), and friction (as the bullet moves down the barrel). All of the energy released by burning of the propellant is accounted for, but not all of it goes into moving the bullet. We can write a simple equation to describe this as follows:

$$\text{CE} = \text{KE} + \text{Other “lost” energy}$$

Suppose the propellant in a cartridge of ammunition contains the equivalent of 1000 kcal (kilojoules) of energy and that the combustion is 25% efficient. This means that 25% of 1000 kJ are converted to kinetic energy of the bullet. Because we know the formula for kinetic energy, we can estimate the speed of the bullet:

$$\text{KE} = 1/2\,mv^2$$

$$250\text{ kJ} = 1/2\,mv^2$$

$$\sqrt{(2 \times 250\text{ kJ})/m} = v$$

Additional work is needed, such as conversion of units to be compatible, but this is beyond the scope of our discussion. Rest assured that, with a bit of algebra, we can calculate a velocity in meters/second or feet/second, which is referred to as the *muzzle velocity* of the ammunition. This is a simple example of the types of physics calculations used in forensic engineering. (For a discussion of career preparation for this field, see Sidebar 18.1.) It's all about tracking the energy and determining the consequences of delivering energy from one place or object to another. To stick with our bullet example, the kinetic energy imparted to the bullet is delivered to the target, usually with devastating consequences. This idea can be expanded to collisions between cars in which the kinetic energy of one vehicle combines with the kinetic energy of another. Similarly, we can estimate the energy transferred from a jet liner full of fuel to a stationary building and begin to understand why the building collapses.

## 18.2 Vehicular Accidents

In 1900, there were only 8000 cars registered in the United States. Amazingly, by 1915 there were 2,332,426 registered cars in the United States. The rapid adoption of motor vehicles by the public is similar to the social change stories associated with the telegraph and telephone, radio, television, personal computers, and cellular telephones. All of these marvels compressed time and distance and promoted personal independence. From the beginning, motor vehicles had sufficient mass and velocity to cause serious accidents when they ran into buildings, objects, animals, and people. By 1915, there were sufficient numbers of them to frequently crash into one another as well.

Except for the years during World War II when civilian vehicle production was halted, the number of registered cars in the United States has steadily increased with population. In 2010, over 250 million vehicles were registered, including over 190 million passenger cars. Of course, these figures do not include trucks of all sorts, including sport utility vehicles (SUVs), motorcycles, mopeds, buses, public vehicles, military vehicles, and nonregistered vehicles such as all-terrain vehicles, tractors, and go-carts. Although the statistics of deaths and injuries on our roadways are sobering, there is an optimistic side to them. Thanks to improvements in safety, the death rate has declined significantly in the past three decades. In 2010, for example, the death rate was 1.1 deaths per million miles, but in 1977, the death rate was 3.3 deaths per million miles. Thus, the death rate has been reduced by almost two-thirds in less than four decades.

How has this been accomplished? There are three primary reasons. First, and most important, is that more people are regularly wearing seat belts. Survey figures released in 2011 from the National Highway Traffic Safety Administration (NHTSA, http://www.nhtsa.gov/) indicate that 84% of people use their seatbelts. In 1970, however, hardly anyone wore them. This change in cultural attitude toward seat belts was brought about by three decades of persistent public service advertising, driver training classes in secondary schools, and state and local law enforcement. It is no small accomplishment.

Second, there has been a significant reduction in drunk driving. Drunk driving is no longer winked at as it once was, and state and local drunk driving laws are significantly tougher and more consistently enforced. In 1987, more than half of all traffic fatalities were related to drunk driving. By 2010, this figure had dropped to 31%. The credit for this reduction goes to organizations such as Mothers Against Drunk Driving (MADD) and Students Against Drunk Driving (SADD) for vigorously pursuing this issue, as well as state and local law enforcement.

Last but not least, the crashworthiness of cars and vehicles has improved. Safety seats for children are now mandatory. Vehicle interiors have been redesigned to reduce impalement injuries. Air bags and side air bags are now standard features in new cars, as well as crumple zones and impact-absorbing bumpers. Side doors are stronger. Engines have been designed to slide under occupants rather than impale them. Seats have better anchors. Seat belts have evolved from simple two-point lap belts to three-point harness restraints with backlash neck supports. Steering wheel columns are collapsible. Gas tanks and fuel lines have improved. Braking systems have improved. Headlights and taillights have improved. Tires have improved, and so on.

Despite these gains, however, vehicular accidents still have a major economic impact in the United States. The economic losses due to vehicular accidents were about $245 billion in 2010. This includes lost wages, legal expenses, medical expenses, funeral expenses, insurance administrative costs, and property damage. A fatality accident currently costs perhaps just over $1 million computed on the basis of an average discounted lifetime, and alcohol-related accidents are still responsible for approximately one-third of all economic losses.

### 18.2.1 Primary Causes of Vehicular Accidents

Table 18.1 provides a list of the reported causes of vehicular accidents in 2009 as summarized by the National Safety Council (NSC, www.nsc.org). The first column reports the causes of accidents in which people were hurt. The second column reports the causes of accidents in which people were killed. The last column reports all accidents, including fender benders, in which no one was hurt or killed.

Not explicitly listed are crashes attributed to distracted driving due to the use of cell phones (calling or texting) or other activities such as working with a global positioning system (GPS), eating, or attending to children. Also included in this category would be sleeping, fatigue, or talking with passengers. The NSC estimates that about a quarter (23%) of all crashes involve cell phone use either as a phone or for texting.

You may note that the category "equipment failure" is not listed. This is because it is not as significant as the other factors. Consistently through the years, the three most significant causes of improper driving have been excessive speed, right of way, and failure to yield. These three categories combined represent the causes for half of all vehicular accidents. The other significant factor is alcohol and drugs. Even though there have been significant reductions in the number of accidents caused by alcohol and drugs, this category still constitutes the underlying cause for approximately one-third of all accidents.

**TABLE 18.1**
**Causes of Vehicular Accidents in 2009**

| Reported Causes of Vehicular Accidents | Injury Accidents (%) | Fatal Accidents (%) | All Accidents (%) |
|---|---|---|---|
| Improper driving | 55.9 | 59.5 | 54.4 |
| Excessive speed | 6.6 | 15.7 | 5.9 |
| Right of way | 15.1 | 10.9 | 13.2 |
| Failure to yield | 10.4 | 7.2 | 9.6 |
| Failed to stop at sign | 2.1 | 2.2 | 1.9 |
| Disregard of signal | 2.6 | 1.5 | 1.7 |
| Driving left of center | 1.5 | 6.9 | 1.2 |
| Improper passing | 0.8 | 0.9 | 1.1 |
| Improper turn | 2.2 | 0.9 | 2.0 |
| Following too close | 6.9 | 1.0 | 9.3 |
| Other improper driving | 22.8 | 23.2 | 21.7 |
| No improper driving stated | 44.1 | 40.5 | 45.6 |

*Source:* NSC, *Injury Facts*, National Safety Council, Washington, DC, 2011.

**TABLE 18.2**
**Fatal Accidents in 2009**

| Category | Percentage |
|---|---|
| Collisions between vehicles | 39 |
| Collisions with fixed objects | 32 |
| Collisions with pedestrians | 15 |
| Non-collisions | 11 |
| Collisions with bicycles | 2 |
| Collisions with trains | <1 |
| Collisions with animals or horse-drawn vehicles | <1 |

Table 18.2 summarizes what vehicles most commonly collide with when there is a fatality. Not unexpectedly, nearly half of all fatal accidents involve collisions with other vehicles. Approximately one-fourth of all fatalities involve collisions with fixed objects, such as telephone poles, bridge abutments, concrete walls, overpass piers, and trees. The category “non-collisions” includes accidents such as driving off a cliff or into a lake.

From these statistics, it follows that most vehicular accident evaluations include determining the speed of the vehicles at the time of the accident, the relative positions of the vehicles with respect to yielding or right-of-way requirements, adherence by the drivers and pedestrians to traffic signs or controls in the area of the accident, whether a driver is sober, and so on. In short, most accident evaluations attempt to determine which of the “cause” categories in Table 18.1 might be applicable.

### *18.2.2 Analytical Tools Used to Evaluate Accidents*

The two most important analytical tools used by engineers in vehicular accident evaluations are the laws of **conservation of momentum** and **conservation of energy**. We discussed the law of conservation of energy in Section 18.1, and we will introduce concepts of momentum shortly. The application of these principles is usually feasible, given the facts and information usually contained in police accident reports. A well-prepared police accident report usually notes skid mark lengths, final vehicle positions, initial travel directions, and the point of impact, either directly or implied. This constitutes most of the usual data needed to solve momentum and energy equations.

Verifiable physical evidence in vehicular accidents usually includes tire and skid marks, a representational plan of the accident area, the location and depth of impact damage on the vehicles and other damaged items observed at the scene, the mechanical condition of the vehicles, the type and location of impact debris noted at the scene, paint transfer marks and other vehicle-to-vehicle and vehicle-to-object contact marks, road conditions, weather conditions, and the physical and mental conditions of the drivers. Other information that could bear upon the causation of the accident includes specific vehicle model performance, roadway specifications, type and placement of traffic control devices and signs, and date and time of the accident.

Although eyewitness accounts of the accident are important sources of information, they must be carefully scrutinized. Distance, lapsed time, and speed—the key elements of most vehicular accident evaluations—are difficult to judge accurately even for an experienced observer. Further, drivers involved in the accident are notorious for underestimating their own speed and overestimating the speed of the other driver.

### 18.2.3 Converting Scene Data into an Event Sequence

An engineer or investigator often does not have the opportunity to examine an accident scene before it is cleaned up and the vehicles are towed away. In fact, it is typical for an engineer or investigator to be assigned the analysis of an accident days, weeks, or perhaps even years after the actual event. For this reason, detailed scene documentation is very important. Facts missed during the initial information-gathering stage at the time of the accident can make or break a court case years later. It is difficult, however, to unerringly determine at the time of the accident which facts will be contested and which facts will be accepted without a problem at a trial many months or even years later. In general, the following information is typically available to assist in analyzing a vehicular accident:

1. Police accident report
2. Photographs of the accident scene and accident vehicles taken by the police or insurance adjusters
3. The accident vehicles that have been towed to a salvage lot
4. Statements of the involved parties and witnesses

A good police accident report is generally fundamental to a good accident reconstruction analysis. In addition to providing the basic information of when, where, and who, a good police report will

1. Diagram the position of the vehicles as found after the accident.
2. Diagram the tire marks, impact marks, impact debris, and other items found at the scene.
3. Contain statements made by the involved parties or witnesses directly after the accident.
4. Contain photographs taken at the time the scene was being worked by the authorities.

After an accident, the vehicles may be impounded by the local authorities in a salvage yard. This may provide an opportunity to make measurements, perform tests, photograph, and otherwise document the condition of the vehicles. It is a good idea to relate marks or debris noted by the police at the accident scene in the accident report to damage observed and measured on the vehicles. Whenever possible, it is best to view firsthand the vehicles involved in the accident. A person never knows what he or she will readily see that was missed by everyone else (Figure 18.1).

In transporting the vehicles from the accident scene to the salvage yard, additional damages or modifications may occur that are unrelated to the accident itself. For example, doors may have been cut off to extricate victims or flat tires may have been fixed so that the vehicles could be towed. The vehicles may have been roughly handled, dragged, or dropped to be placed in rows or particular parking slots in the salvage yard. Sometimes, parts are stolen along the way or after the vehicle has been in storage for a time, especially radios, CD players, headlights, grilles, hubcaps, tires, and easily sold items. Such post-accident changes to the vehicles should be noted and segregated from the analysis of the actual accident damage (Figure 18.2).

Some **accident reconstructions** are done long after the vehicles have been scrapped. Most cities or states retain an accident vehicle only for a short time. In lieu of the actual vehicles, the engineer may have to rely on photographs taken

***Figure 18.1*** Skid marks at accident scene. Barber pole pattern in skid mark indicates tire was rolling forward at same time it was skidding sideways.

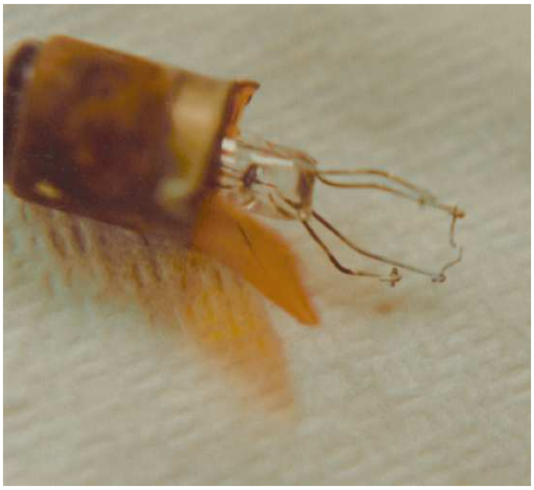


***Figure 18.2*** Distended lamp filament shows that light was on at time of impact—a very useful piece of information.

by the police or an insurance adjuster. By applying reverse descriptive geometry drafting techniques, it is sometimes possible to determine the dimensions of crush, impact area, and other accident parameters from photographs.

After all the aforementioned data are examined and assessed, it is a good idea to outline the accident scenario chronologically in general terms. Many engineers and investigators do this in reverse because the place where the vehicle or vehicles came to rest is often the most well-established fact. Alternatively, some investigators initially write down both the first and last events because the beginning point is often well established also, and then they begin to list what happened between the two endpoints.

In any case, a basic accident scenario, or reconstruction, is outlined in general terms, and then details are "worked" into it until the scenario contains all the known facts in a logical sequence. This is done before any engineering analysis is done. Later, when the engineering analysis is done to determine speeds, directions, and other computed data, the computed data are added to the scenario as details. Of course, the computed details must be consistent with the known physical facts as well as the known physical laws and constraints. If not, further modifications may be needed until it is. If the scenario is laid out logically, a major reconstruction faux pas or inaccurate witness statement is relatively easy to detect. The end product of this process is the accident reconstruction scenario.

### *18.2.4 Accident Reconstruction: Energy*

As we discussed earlier, the conservation of energy law states that, in any physical process, the total energy of the system at the beginning of the process is equal to the total energy of the system at the end of the process. The total energy at the end of the process includes any **irreversible work** done during the accident event. Irreversible work simply means that once some energy is used for a particular process it cannot be converted back into the kinetic energy it once was. In an irreversible process, the change from one energy type to the other is one way. An example of irreversible work is **skidding**. The initial kinetic energy of the vehicle is converted to irreversible work as tires rub against pavement and brake pads rub against brake disks. In our example of a gun, irreversible work would be the rubbing of the bullet against the barrel as it is accelerated outward.

When a vehicle is moving, it possesses kinetic energy. The amount of kinetic energy it has depends on its mass and how fast it is going. The faster it moves, the more kinetic energy it has. Conversely, when a vehicle is not moving, it has no kinetic energy. It follows, then, that bringing a vehicle to a stop requires that a vehicle's kinetic energy be reduced to zero (Figure 18.3). Because the total energy at a given speed is constant, reducing a vehicle's kinetic energy to zero requires that it be converted into another type of energy, something other than kinetic. In most accidents, this is done by using the kinetic energy to do some type of irreversible work, such as braking, skidding, or various types of crushing, twisting, or bending.

***Figure 18.3*** Typical truck "duals" skid mark. Straight lines in skid marks indicate tires not rotating much, or rotating and skidding in the same forward direction.

The kinetic energy of a vehicle is the same as for a bullet, with different assignments of variables:

$$\mathrm{KE} = 1/2 \times m \times v^2$$

where
KE = Kinetic energy
$m$ = Mass of the vehicle
$v$ = Velocity of the vehicle

Because velocity is squared, doubling the velocity increases the kinetic energy by a factor of four. This is why the braking distance for a vehicle traveling at 60 miles per hour (mph) is approximately four times more than the braking distance of the same vehicle traveling at 30 mph. Damage severity and injury severity, like braking distance, also increase in direct proportion to the square of the velocity.

When a vehicle comes to a complete stop in the normal way, its kinetic energy is reduced to zero by applying the vehicle's brakes. The brake pads rub against a disk or drum, and the friction between the two surfaces converts the kinetic energy of the vehicle into irreversible work. Some of the energy is used to abrade away material on the two rubbing surfaces; some of it is converted into heat. As the vehicle's kinetic energy is dissipated, the vehicle slows. When all the energy has been dissipated, the vehicle stops.

In an accident, the initial kinetic energy of a vehicle can be dissipated in many ways. One of the most common ways is skidding. To see how this works, consider the following example of a simple skid: A car skids 100 feet to a stop on dry concrete pavement. Halfway through the skid, the car strikes a pedestrian. How fast was the car going just before the driver applied his brakes and initiated skidding, and how fast was the car going when the pedestrian was struck?

Because the definition of work is force applied through a distance, the irreversible frictional work done in skidding 100 feet on dry concrete pavement is given by the following formula:

$$E_{work} = (mg) \times f \times d$$

where
$E_{work}$ = Work done by skidding
$m$ = Mass of the vehicle
$g$ = Acceleration of gravity (32.17 ft/s$^2$)
$(mg)$ = Weight of the vehicle and its contents (mass × acceleration of gravity)
$f$ = Frictional coefficient between the tires and the pavement, which is about 0.75 in this case
$d$ = Distance skidded

If the kinetic energy of the car before skidding is set equal to the energy dissipated by skidding and then we apply algebra to simplify the results, the following is obtained:

$$\text{Energy start} = \text{Energy end (energy is conserved)}$$

$$\mathrm{KE} = E_{work}$$

$$(1/2)mv^2 = (mg) \times f \times d$$

$$v = [2gfd]^{1/2}$$

***Figure 18.4*** Skipping truck skid marks are usually the result of light trailer load or when trailer brakes alone are used. Measure the whole length; do not omit "skips."

Thus, the initial speed of the vehicle just before skidding began can be computed by measuring the skid mark. The other values in the formula—$g$ for the acceleration of gravity and $f$ for the tire-to-pavement frictional coefficient—are already known. This formula, or variations of it, is widely known as the **skid formula**. Most police officers who have had some formal accident reconstruction training at an academy are familiar with the use of this formula.

In our example, where the skid mark was measured to be 100 feet long, the initial speed of the vehicle is calculated to have been 69 feet per second (fps), or approximately 47 mph just before the skid began. To determine the speed of the vehicle when the pedestrian was struck, a person can simply work backward from where the vehicle stopped to where the pedestrian was struck and then reapply the skid formula. In this case, the car skidded 50 feet after striking the pedestrian. Thus, the speed of the car when it struck the pedestrian is equivalent to a skid of 50 feet. This computes to a speed of 49 fps, or approximately 33 mph.

This result is notable. If the driver had been traveling at the posted speed limit of 35 mph or less, it is possible that he might have been able to come to a stop, or almost come to a stop, in 50 feet. Fifty feet is the distance in which the driver responded after recognizing the situation. Because the driver was not traveling at or less than the posted speed limit, but was traveling at 47 mph or perhaps more, he could not stop within 50 feet. Consequently, excessive speed is an important factor in both the cause and severity of the accident. Being struck by a vehicle at 33 mph is certainly very different in severity from being struck at 2 mph (Figure 18.4).

Another way that kinetic energy can be dissipated in an accident is by crushing the front end. It takes work to push in the front end of a vehicle. Most people know by experience that if a car impacts an unforgiving, massive brick wall, the faster the car impacts the wall, the deeper the front end is crushed. Although each make and model of vehicle has its own specific crush vs. speed relationship, vehicles within the commonly accepted vehicle categories tend to have similar crush vs. velocity relationships. The commonly accepted categories for cars in this regard are mini-compact, subcompact, compact, intermediate, full size, largest size, and miscellaneous, which is a category for very large passenger cars. Each year, both government and private organizations test vehicles to determine how much they crush for various speeds and conditions. Some agencies process this raw data into a composite rating for crashworthiness, as is done each year by *Consumer Reports*.

Passengers in the vehicle are also subjected to the effects of the kinetic energy involved in the accident. Without a seat belt or air bag to provide cushion and absorb the kinetic energy of the driver's body, the driver would otherwise be thrown into the steering wheel, dashboard, and windshield area at a speed of 19 mph. This is the equivalent of a fall from about 19 feet. The driver would then impact the steering wheel and dashboard, and decelerate at 20 $g$ (gravitational acceleration) to a stop in 14 inches. A couple of additional inches might be gained due to interior crush of the steering wheel. This would be very tough on a person's body. It would likely result in serious injuries or death.

The preceding two simple examples demonstrate the usefulness of the energy method. Because of the variety of damages that can be done by a vehicle in an accident, it is not possible in a single chapter to give examples of all the ways energy dissipation can be calculated. Some of the techniques require a higher level of mathematics than basic algebra, but the basic essence of the method is this: The initial speed of a vehicle can be computed by accounting for all the irreversible work done by that vehicle to bring itself to a stop. Accurate results are obtained when all the ways in which the vehicle dissipated energy are accounted for.

In cases where not all of the work terms can be accounted for, the energy method can still be useful. The method can provide a lower bound for the speed of the vehicle. In other words, if an irreversible work term is left out, the computed speed of the vehicle will be less than the actual speed. Sometimes this is enough. For example, if the lower-bound estimate of the speed of a vehicle found that it was going at least 70 mph in a 20 mph zone, knowing precisely the actual speed of 76 mph may be moot.

### *18.2.5 Accident Reconstruction: Momentum*

**Momentum** describes the state of motion of an object such as a car. Mathematically, it is calculated as the mass of the object multiplied by its velocity. When objects such as vehicles collide, they exert equal but opposite forces on the other. Because of this, the combination of two vehicles colliding does not cause any change in total momentum. The sum of the net forces between the two vehicles is zero because they are equal and opposite to each other. Thus, as long as there are no external forces being applied on the vehicles, during a collision the net momentum of the vehicles just prior to the collision is equal to the net momentum just after the collision. The preceding is a definition of the law of conservation of momentum.

There are two basic types of collisions: elastic and plastic. A fully **elastic collision** between two bodies is one in which the deformation of each body obeys **Hooke's law**. Hooke's law states that, within certain limits, the deformation of a material is directly proportional to the applied force causing the deformation. A more practical working definition of an elastic collision is one where the two bodies return to the same shape after the collision that they had before the collision. With respect to passenger cars, elastic collisions occur only at very low speeds, 2.5 mph or less. Because injuries and damages at this level of speed are relatively small, the analysis of fully elastic collisions between passenger cars is of more academic than practical significance.

In a **plastic collision**, or non-elastic collision, the deformation in the contact zone of each body does not follow Hooke's law. A significant portion of the deformation is permanent. Once dented and smashed, it stays dented and smashed. Nearly all vehicular accidents of significance are plastic collisions. Consider the following simple example. The driver of a 2500-lb car is sitting at a light waiting for it to turn green. The driver has his foot firmly on the brake pedal so that the brakes are fully engaged. A driver of a 4000-lb SUV is texting while driving and approaches the first driver from the rear and is in the same lane. The driver of the SUV does not see the driver of the car and drives right into him. After impact with the car, the driver of the SUV quickly applies his brakes. The car leaves a skid mark 25 feet long. The SUV leaves a skid mark 13 feet long. How fast was the SUV traveling when it initially struck the car?

In qualitative momentum terms, the accident scenario is as follows. The SUV had an initial speed and momentum. When it struck the car, some of its momentum was imparted to the car, which caused it to lurch forward. The remainder of the momentum stayed with the SUV, but its speed now was slower because it lost some of its momentum. Prior to the collision, the car had no momentum because it had no velocity. All the momentum was supplied by the SUV. Consequently, the combined momentum of the car and SUV after the collision is equal to the momentum of the SUV alone before the collision. We can use some relatively simple calculations (not shown) to show that the SUV was initially going at 31 mph when it struck the rear of the car. The car was initially pushed forward at 23 mph and then came to a stop by skidding, and the SUV slowed down to 16.5 mph due to the impact and also came to a stop by skidding. The car came out of the collision traveling a little faster than the SUV, which allowed the two vehicles to separate.

Not only does this example demonstrate the use of the law of conservation of momentum to determine the speed of a vehicle prior to impact, but it also shows how the energy method and the momentum method are often used together to obtain a complete solution. The "after impact" speeds of the vehicles were computed from the skid marks using the energy method, whereas the "before impact" speed of the SUV was computed using the momentum method. One method supplied information for the other.

It is also possible to determine the "before impact" speed of the SUV by measuring the crush depth at the front of the SUV and at the rear of the car, and equating the work needed to create the crush in both vehicles to the "before impact" kinetic energy of the SUV. By doing this, the "before impact" speed of the SUV would then have been computed using two independent methods. In cases where there is sufficient information to compute the speed of a vehicle using two independent methods, and the two solutions reasonably converge, this tends to affirm that the solution is correct. It is an excellent way of checking the accident reconstruction.

## 18.3 Solution Strategies

There are many methods and strategies for investigating, understanding, and reconstructing accidents and many factors and contributors to be considered. We will look at only a few in this chapter. One factor of increasing importance is distracted drivers. In a vehicle search, items in the driver's area may indicate whether the driver was fully attentive at the time of the accident. Open maps, open books, open newspapers, cell phones in the open position, food scattered and splattered on the top of the dashboard and windshield, or makeup items in an open position and scattered on the top of the dashboard may indicate that the driver's attentions were elsewhere. Cell phones indicate the time and telephone number of the last call or text message sent. This can be useful in determining if the driver was talking on the telephone when the accident occurred. When the physical evidence indicates that there were things going on in the driver's field of view, but the driver indicates that the other car "came out of nowhere" or "I never saw him," this is suggestive that the driver's attention was focused on other tasks. Sound level is also an important indicator of attention. Warning signals, such as the horn on a locomotive, train crossing bells, emergency vehicle sirens, and the horns of other vehicles cannot be heard by the driver if the noise level inside the vehicle is too loud. A rule of thumb to use is that for an external noise to be perceived it should be at least three decibels higher in intensity than the ambient noise level. For this reason, it is useful to check the position of volume control knobs on radios, CD players, and similar, and to verify whether the side windows were up, the air conditioner or heater was on, and so on.

In intersection-type accidents, the width of a person's peripheral vision can be important. A person who regularly only perceives objects 50° on either side of dead ahead may not be cognizant of a vehicle that is 60° from the center of his vision and is approaching fast. It is useful sometimes to chart the visual angles of the vehicles involved in an accident to determine who could see whom, and when.

The **vehicle identification number (VIN)** is usually located at several points in a car, most notably at the base of the windshield, left-hand corner of the driver's side, and also on the inside of the driver's side door. With a vehicle's VIN it is possible to (1) determine whether it has been brought back to the dealership to have a recall item fixed, (2) determine the maintenance that has been done on the vehicle at authorized dealerships, (3) determine at which dealerships the maintenance was done, and (4) track whether the vehicle has been stolen or involved in previous accidents. Coded into the VIN is the vehicle type, the factory where it was made, and the year and week it was built. Most car companies encode the VIN in a bar code so that it can be read by a scanner from the outside of the windshield.

### *18.3.1 Identification of the Driver*

A common question posed to an accident investigator is who was driving at the time of the accident? The question can be especially important when there is only one survivor. The estates and families of the deceased occupants may wish to sue the driver of the vehicle for wrongful death, negligence, or something similar. It may be that the survivor was found after the accident to be very drunk and is subject to criminal prosecution if he actually was the driver.

When the occupants in a car do not wear seat belts, the identification of the driver is generally easy. Often at impact, the unbelted driver will be hurled against or through the windshield in the direction of impact. If the driver was hurled against the windshield but the windshield did not break, it is probable that hair and tissue of the driver will have been left in the "spider" crack pattern in the windshield where his head or face impacted. If the driver was the only one in the car with blond hair, for example, it can be as easy as examining the hair found in the spider cracks under low magnification to verify color.

Because the driver has the steering wheel in front of him, if he is not seat-belted then the steering wheel will often cause easily identifiable injuries. Bruises in the shape of a steering wheel are an obvious giveaway. Where the steering wheel has been bent or damaged, the driver will often have corresponding injuries. If a driver is injured and bleeds in the car, the blood DNA of the stains and a profile can be determined and matched to the occupants. This type of chemical analysis, however, requires the services of a specialized laboratory, which may not be readily available in some areas. It is important not to inadvertently cross-contaminate the sample locations so that this evidence is not disputable.

The position of the other occupants at the time of the accident may be determined by reviewing each person's injuries with respect to his or her trajectory through the vehicle after impact. For example, a person in the back seat may be thrown forward between the two front seats headfirst into the dashboard. This person would have head and shoulder injuries consistent with this trajectory.

### *18.3.2 Component Failures*

Sometimes, the cause of a crash or accident is blamed on the failure of an important metal part (see Case Study 18.1). It may be claimed that the part failed first, which then precipitated the accident. In such cases, it is important to examine the fracture and determine its metallurgical characteristics. A hardness test will determine its approximate strength and provide information as to whether it has been heat treated. The type of fracture is also very important. A **fatigue-type fracture** indicates that

**CASE STUDY 18.1: THE *COLUMBIA* ACCIDENT IN 2003**

In 1986, the space shuttle *Challenger* was destroyed 73 seconds after launch and the seven astronauts aboard, including a school teacher, died. Forensic engineering was critical in the investigation, which showed that a faulty O-ring was a primary cause. In 2003, the shuttle *Columbia* was lost on re-entry. Again, forensic engineering was used to reconstruct what happened and why. Eventually, it was shown that a piece of foam used to insulate the fuel tank broke off at launch and hit the left wing of the shuttle. This damage was sufficient to cause the accident and take the lives of another seven astronauts. See Figure CS18.1.1.

***Figure CS18.1.1*** Forensic engineering was used to reconstruct the *Columbia* accident.

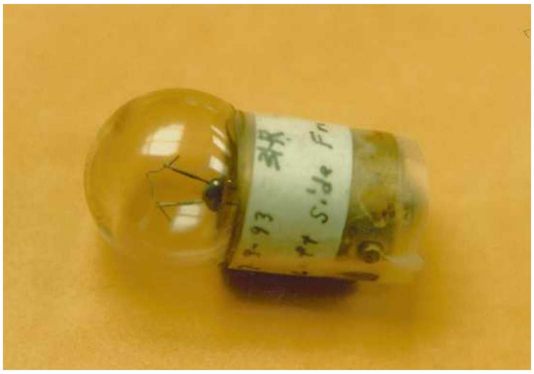


***Figure 18.5*** Distended lamp filament used to prove that the left-side front signal light was on at the time of the accident.

the part has been partially cracked for some time before the accident. Thus, it can be argued that the part was weak at the time of the accident and susceptible to failure (Figure 18.5).

A **shear fracture**, **tensile fracture**, or **bending fracture** with no indication of fatigue usually indicates that the part failed at the time of the accident, perhaps being damaged as part of the accident process. This is especially true when the fracture surface is new and no evidence is present that the fracture existed prior to the accident, such as rust, corrosion, or extensive discoloration due to exposure to exhaust fumes or oil.

Sometimes, when a car has undergone previous repair work, the mechanic may have used an inferior replacement part. Nuts and bolts, for example, are not all the same simply because they fit. Some nuts and bolts are made of stronger material than others. If a high-strength nut or bolt is replaced with a common grade item, it is possible that the replacement will not perform properly. It may back off, rust, or corrode prematurely, or it may simply fail due to weakness. There are known cases of “bootleg” nuts and bolts. These are components that display the markings of a high-strength component but are actually low-strength, cheap substitutes designed to bilk the buyer.

In a similar vein, improper weld repairs may sometimes precipitate mechanical failure. Many vehicles have frames made of high-strength alloys that have been heat-treated. If a body shop attempts to weld these alloys in the usual way, the weldment will not have the same characteristics as the original metal. There will also be metallurgical changes in the base metal immediately next to the weldment, the **heat-affected zone (HAZ)**. Usually, the material in the HAZ is weaker and more susceptible to fatigue than the original base material. This can often be detected by a hardness test profile across the suspect weldment.

Tires are often blamed for causing accidents. The most common failure occurs when a tire is underinflated. When this occurs, the bending stresses in the tire wall are greatly increased, and the tire carcass heats up. Because the strength of the rubber and carcass is sensitive to temperature, the tire wall will have less mechanical strength at the elevated temperature. The combination of high temperature and increased bending stresses causes the materials in the tire to fatigue. Eventually the tire fails, often by a blowout.

A tire that blows out due to under-inflation will usually have a blowout in the tire wall. It often will be located at the point of maximum bending in the tire wall. If a tire has been run underinflated for a time, the point of maximum bending can often be clearly observed by discoloration of the tire wall in that area. There will be a boundary line that runs around the tire at a more or less constant radius from the center. It will be dark on one side of the line and normally colored on the other.

The “hardness” of a tire or other rubber-type product, including many plastics, is measured with a **durometer**. If a tire has been run underinflated, the durometer number of the heat-affected tire will be measurably lower than that in areas that were not subject to the excessive bending stress and heat buildup. A durometer profile of the tire can be taken across the tire to map out the extent of softening that occurred before the blowout.

When a tire blows out due to underinflation, the point where the blowout occurs will exhibit **material fatigue**. The cord fibers that failed first will be frayed unevenly and will have a disheveled, even dirty appearance. This will be in contrast to fibers that simply snapped in tension later on when the tire failed generally. Where the bending stresses are highest in the tire wall, usually at a point closest to the exterior surface, the fibers will have come loose from the rubber matrix and may have even “wallowed” around in the matrix. This is in contrast to the fibers in the rest of the tire, which may still adhere fast to the matrix.

When a tire fails some time before the accident, it will often be damaged by having been run flat. There may be cuts in the tire from the rim, and even holes where the pavement abraded away material if the brakes were locked. If the wheel continued to roll for a time after the tire lost air, the rims may be damaged and rim marks may be visible in the pavement. The presence of rim marks along the accident pathway of a vehicle is often used to determine when a tire went flat. Examination of the tire tread can also provide significant clues as to whether the tire was consistently run with low or high pressure. A consistently underinflated tire will have greater tread depth in the middle than at the edges. Conversely, a consistently overinflated tire will have less tread depth in the middle than at the edges.

Impacts to tires by potholes, curbs, and roadway edges can be severe enough to cause a tire to lose air and deflate. Often, the rim will be bent where the impact initially occurred with the curb or whatever, and this will also correspond to tire damage at the bead. Because most late-model cars and trucks use tubeless tires, damage to the tire bead by impact will usually cause the tire to lose seal and deflate. Naturally enough, when a tire fails due to punctures from something on the road like a nail or sharp object, the puncture will occur in the tread portion of the tire. Dismounting the tire and inspecting the tire interior may occasionally find the article responsible for the puncture embedded within the tire itself. Damage from a sliding contact with a curb or curb offset will usually cause damage to the outer sidewall of the tire.

### *18.3.3 Point of Impact*

**Point of impact (POI)** is often the most contested issue with respect to the scene examination of an accident. In some states, it is not even permitted to discuss in court the issue of point of impact or to even use the term. This is because of questionable past practices in accident reconstruction that used what is often called the **debris method**. The debris method is simply an examination of the scene for debris on the ground at the accident scene, for things such as headlight glass, turn signal lens parts, and other parts that were damaged on the vehicle. The general area where these items are found is mapped out and the center of the area is sometimes considered the point of impact (Figure 18.6).

***Figure 18.6*** Skid pattern showing car was rotating counterclockwise as it crossed over to the oncoming side and struck a tree.

This is a poor method because it does not take into account the difference in speeds between an impacting vehicle and the times separated from the vehicle by impact. The debris items may actually travel and come to rest several yards from where actual impact occurred. Because of ricochets and glancing impacts, debris can be hurled in directions that do not correspond to any vehicle's direction of travel. However, as practiced, the method often assumes that accident events occurred more or less in the same area where the debris was found. Sometimes, when a collision has damaged the radiator or engine, the position of spilled liquid would be called the POI. In itself, this is also poor practice. It may take some time for fluid to drip down onto the pavement. In the time it takes to begin flowing and drop down, the car may have moved significantly away from the actual POI. The position of pooled fluids does, however, mark the location of the vehicle after it has come to rest and can be a useful reference point after the vehicles have been removed from the scene.

A more accurate method for determining the POI is to look for gouge marks or telltale tire marks. A skid, rim mark, or other tire mark that suddenly deviates in a new direction can be a good indicator of the POI. A severe head-on collision will sometimes cause the front tires to become flat due to downward forces. A skid mark that terminates at a short rim mark or rim gouge will often denote the POI in such cases.

When impact occurs, other parts of the car may be damaged and be pushed down to the pavement, making gouges at or leading away from the POI. Tie rod gouges and bumper gouges are common in severe collisions in which the parts were immediately detached and forcefully pushed down into the pavement (Figure 18.7).

***Figure 18.7*** Paint transfer marks in contact are "tag" marks and can be chemically compared to the other vehicle to confirm who hit whom.

### 18.3.4 Automatic Recording of Data Related to Accidents

The **accident avoidance strategy** approach assumes that certain parties to the accident traveled at the legal speed and performed reasonably in all their actions including braking, turning, and accelerating. This presumption is then compared to the actual events that occurred. If there is a significant difference between the two scenarios, the difference lends itself to an explanation of what occurred.

When air bags began to be installed in cars in the late 1970s, a "trigger" computer chip was also installed to tell the air bag equipment when to deploy. Initially, this was a simple accelerometer connected to a logic circuit. When the acceleration, or change of speed per change of time, exceeded a certain value, as might occur if a car were impacting a telephone pole, the chip would send a signal that caused the air bag to deploy. Later, to ensure that the bag would not deploy inadvertently, additional parameters were added (e.g., bumper movement or brake pedal actuation) to ensure that the car was really involved in an accident.

Recent car models are now being equipped with black-box recorders. Manufacturers such as Ford and GM have realized the possibility of obtaining real-world performance information about their safety equipment directly from the field. Most current air bag computer chips can record the performance of a vehicle during the last 5 seconds before a crash. Parameters commonly recorded include vehicle velocity, engine revolutions per minute (RPM), throttle position, seat belt engagement, and brake actuation. All of these parameters can be downloaded through the vehicle's diagnostic patch and plotted against time. Not only is the information useful for automobile designers to improve the performance of their products, but it is also very useful in court cases.

In August 2003, for example, despite various legal objections, police in South Dakota obtained and used black-box data from a Cadillac as evidence in the hit-and-run trial of Congressman Bill Janlow. Due to the publicity this case and other similar high-profile black-box cases have received, black-box data are now often subpoenaed and used in lieu of engineering analysis, or as a supplement to it. The black box is perceived by many as an impartial third-party witness to the accident.

Many cars and trucks also come equipped with combined global positioning system (GPS) and automobile cellular telephone devices that automatically indicate to a central office when and where an accident has occurred. When such an accident occurs, a dispatcher is alerted by a signal and calls the vehicle, makes inquiries, and summons the appropriate help. The conversations of the dispatcher with the driver and the authorities that are summoned is recorded. This conversation may be subpoenaed as evidence in a later trial.

Similarly, many new and old vehicles are now equipped with GPS direction finder devices. New vehicles may have built-in units, but older vehicles may be equipped with aftermarket units made by the same companies that perform the same function. Many of these devices are essentially GPS data loggers. Depending on how they are programmed or configured by their owners, these devices can preserve and provide plots of the vehicle's speed and position vs. clock time during a trip. Rather than recording just 5 seconds of dynamic data prior to an accident, these devices can record a vehicle's speed and position vs. time for an entire trip. There have been recent court cases where such GPS recorded data have been used to disprove speeding tickets. In one case, the driver disputed a speeding citation based on a radar gun measurement by a police officer. The driver claimed that the radar gun was out of calibration and measured incorrectly. The driver won his case by offering alternative data: his own GPS device's record of his vehicle's speed at the time and location the officer was using the radar gun.

In short, vehicular accident analysis is rapidly becoming automated. The ability to record on-the-spot statements about an accident from the drivers and passengers, the ability to exactly note the location and time of an accident, and the ability to apparently impartially provide speed and location information about both vehicles seconds even hours before an accident occurred, before the police or emergency personnel even arrive at the scene, not only currently exist but are becoming routine.

## 18.4 Structural Collapses

We can extend our understanding of energy and momentum to a different type of engineering challenge—understanding why structures such as bridges and buildings fail. Particular structures, such as the Great Pyramid of Cheops, the Taj Mahal, or the Golden Gate Bridge, symbolize aspects of a culture. Building methods, materials, and architectural style can even be used to broadly characterize a civilization. Distinguishable architectural details among buildings and structures can then be used to separate eras within a particular civilization. For example, the New York skyscrapers built in the 1930s are readily distinguishable from the New York skyscrapers built in the 1970s, despite the fact that both groups characterize the skyline of modern New York. Once a structure is erected, factors such as corrosion, weather, various aging effects inherent in the choice of materials, original design mistakes, abuse, unexpected loads, and external forces all work together to bring a building down. These items can be divided into two fundamental categories: static load support deficiencies and dynamic load deficiencies.

### *18.4.1 Static Loads*

**Static loads** include the basic weight of the building itself and its contents. A building has to be strong enough to resist gravity and hold itself up. It should do so without excessive deflections and movements that might scare the occupants, make the occupants uncomfortable, or make the building difficult to use. For example, a large foundation settlement in a frame building may allow the floors to sag significantly, which then allows wheeled furniture to slowly slide to the low point, causes doors and windows to jam, and makes walking around an uncomfortable experience.

The static loads of a building are often subdivided into two categories: dead loads and live loads. **Dead loads** are loads that never seem to change in a building, such as the weight of the floors, walls, supports, and roof. **Live loads** are loads that can sometimes change due to weather, occupancy, or building use. They include such things as the temporary weight of snow or ice on the roof, the weight of the people in the building and where they are congregated at various times of the day, and the weight of furniture, machinery, and equipment in the building and how they are distributed.

A building can collapse when its primary structural components do not have sufficient strength to support the applied static loads. This can happen because of an error in original design; an omission or mistake during construction; abuse or neglect of the building; sabotage; external forces such as earthquakes, storms, or floods; use of the building for unintended purposes; or perhaps because of degradation over time by corrosion, wear, or weathering. To compensate for degradation over time, wear, possible minor design mistakes, minor construction mistakes, and certain types of abuse or neglect that can be reasonably anticipated, buildings are designed to support static loads that are several times stronger than what the designer anticipates would typically be needed. This is called the building's **margin of safety**.

### *18.4.2 Dynamic Loads*

**Dynamic loads** are loads on a building that change during a relatively short period of time. They are repeatedly applied and released. Dynamic loads add to the static loads that a building must be able to handle, which means that a building, or perhaps certain parts of a building, must be made even stronger than is required to handle its static loads. Unexpected dynamic loads eat into a building's margin of safety.

Dynamic loads typically include forces due to strong winds, gusting, or winds from varying directions; machinery inside the building or nearby that pounds or shakes the floors and walls; and ground motion such as earthquakes, heavy traffic, or nearby construction work. Dynamic loads, when sufficiently strong and when applied often enough, can cause some materials to fail due to material fatigue. Fatigue is the premature fracture and failure of material due to the repeated application and release of loads. Fatigue can occur even when there is margin between the intrinsic static strength of the material and the sum of the applied forces. In other words, a varying load can sometimes cause failure even when the varying load is less than the static load strength of the material.

A famous example of excessive dynamic loading is "Galloping Gertie," the nickname given to the Tacoma Narrows Suspension Bridge built across the Tacoma Narrows in Puget Sound in Washington in the late 1930s. It collapsed on November 7, 1940, soon after the bridge had been opened to the public. Gertie was a cable suspension bridge, similar in design to the Golden Gate Bridge. When it was built, it was considered to be a notable achievement due to its relatively light weight, great structural flexibility, and architectural grace; however, it tended to sway and "wave" excessively on windy days.

The waves in Gertie were caused by aerodynamically induced dynamic forces applied to the bridge decking that were not anticipated by the designer. Crosswinds under and over the bridge decking caused the decking to alternately lift like an airplane wing and then drop. On November 7, 1940, the crosswinds were sufficiently strong to induce the formation of very large waves in the bridge decking. The alternate lifting and falling eventually tore the decking apart and the decking failed catastrophically. Once failure initiated, the decking fell in a sequential pattern as the deck support connections gave way in order, beginning at one spot about one-third of the way across the bridge and then working its way back to the beginning of the decking. When a failure proceeds in an orderly sequence like this, the result is called a **domino effect**. If a domino effect failure can be interrupted early, the consequential damage can be significantly mitigated.

Fortunately for engineers, Gertie's failure was filmed. The film has been useful to engineers and bridge architects in their study of the dynamic loads induced in suspension bridges by aerodynamic lift. Since the collapse of the Tacoma Narrows Bridge, bridge architects and engineers have included aerodynamic and vibrational considerations in their bridge and structure designs. In some instances, bridge models are tested in wind tunnels.

## 18.5 Building Collapse Due to Impact

Although several buildings were associated with the World Trade Center (WTC), it conspicuously consisted of two very large buildings: One World Trade Center (North Tower) and Two World Trade Center (South Tower). One WTC, completed in 1972, was 1368 feet tall. Two WTC was completed a year later and was 6 feet shorter. Both buildings were 110 stories high and structurally more or less the same. For a short time they were the tallest buildings in the world. The foundation of each building was set about 70 feet into the ground. Each floor enclosed almost an acre of office space.

Structurally, each building was a vertical, hollow, rectangular tube within another vertical, hollow, rectangular tube. The outer rectangular tube consisted of 244 14-inch steel box columns spaced 39 inches apart. The inner rectangular tube was 90 feet long and was composed of tightly spaced steel girders around a central core of elevator shafts and stairways. The inner tube supported much of the weight of the building. The inner tube and the outer tube were connected by steel spandrel members overlaid with steel decking and 4 inches of concrete. The floor decking system supported the 40,000-square-foot floor and also acted as a structural stiffener between the inner and outer rectangular tubes. Each floor system by itself weighed perhaps 3 to 3.5 million pounds. At the foundation of each building, the total bearing load was approximately 1 billion pounds.

At the time the building complex was designed, it occurred to the designers that accidental impact by an airplane was a possibility. The Empire State Building, which is 102 stories, 1250 feet high, and in the same neighborhood as the WTC, was struck by an errant U.S. Army B-25 bomber during a fog in 1945, just 14 years after the building was completed. In that accident 14 people were killed.

When the WTC was on the drawing board, the most probable sort of air accident imagined was the accidental impact by a Boeing 707 jet aircraft when it was either landing or taking off from one of the nearby airports. At the time, the Boeing 707 was the largest commercial aircraft in use. A Boeing 707 has a maximum takeoff weight of about 336,000 pounds, a wingspan of 146 feet, a length of 153 feet, a tail height of 52 feet, and a cruising speed of 607 mph; when fully fueled it contains about 23,000 gallons of fuel. It was presumed that if an impact were to occur, the velocity at impact would be similar to landing or takeoff velocity, perhaps 180 mph.

At 8:46 a.m. local New York time on September 11, 2001, the North Tower of the WTC was struck by a Boeing 767 that was deliberately steered into the building. A second Boeing 767 struck the South Tower at 9:03 a.m.; it also was deliberately steered into the building. Both aircraft apparently impacted the towers at cruising speed in an effort to maximize damage to the buildings (Figure 18.8).

A Boeing 767 has a maximum takeoff weight of about 395,000 pounds, a wingspan of 156 feet, a length of 159 feet, and a cruising speed of 530 mph; when fully fueled it carries about 19,000 gallons of jet fuel. A 767 aircraft is about 18% heavier than a 707 aircraft, and cruising speed is almost three times faster than landing or takeoff speed.

The impact occurred on the North Tower between the 90th and 96th floors. Seismometers located in Palisades, NY, about 21 miles north of the building, recorded a 12-second ground shock with a 0.8-second dominant period that had an equivalent earthquake magnitude of 0.9 on the Richter scale. The impact to the South Tower occurred between the 75th and 84th floors. It generated the equivalent of a 0.7 magnitude earthquake and had a 6-second ground shock with a 0.7-second

***Figure 18.8*** Flight 175 hits World Trade Center South Tower (http://commons.wikimedia.org/wiki/File:UA_Flight_175_hits_WTC_south_tower_9-11_edit.jpeg).

dominant period. Photographs taken of the second aircraft approaching the building indicate that just prior to impact the aircraft was rolled about 45°, with the left wing tip down and the right wing tip up. It was also pitched with the nose downward perhaps 10° and was dropping in altitude as it approached the building.

In the North Tower, the initial impact severed about two-thirds of the steel supports on the tower's north side. Despite this severe structural damage, however, the floors above the impact area did not collapse. After impact, fire immediately broke out in the affected floors and rapidly spread through the crash-affected area, feeding upon the spilled fuel from the decimated aircraft. The North Tower eventually succumbed to the fire and collapsed after 102 minutes at 10:28 a.m. When it fell, it generated the equivalent of a 2.3-magnitude earthquake.

Impact to the South Tower caused similar structural damage to the steel supports. In the resulting fire, which immediately ensued after impact, the South Tower collapsed 56 minutes after impact. This is about half the time that the North Tower stood before fully collapsing. When the South Tower fell, it generated the equivalent of a 2.1 magnitude earthquake. The kinetic energy at impact of each aircraft that struck the towers can be estimated by the same formula we used with vehicles:

$$\text{KE} = 1/2 \times m \times v^2$$

where

KE = Kinetic energy

$m$ = Mass of the aircraft

$v$ = Velocity of the aircraft (530 mph, or 777 fps)

$$\begin{aligned}\text{KE} &= (1/2)(395{,}000 \text{ pounds force}/32.17 \text{ fps}^2)(777 \text{ fps})^2\\ &= 3{,}710{,}000{,}000 \text{ foot pounds force}\\ &= 4{,}771{,}000 \text{ British thermal units}\\ &= 1.40 \text{ megawatt hours}\end{aligned}$$

By way of comparison, a compact car that weighs 2500 pounds and is traveling at 100 mph has a kinetic energy of 836,000 foot pounds force. The impact energy of one of the aircraft was equivalent to about 4439 compact cars all traveling at 100 mph.

The aircraft did not penetrate through the building and come out the other side, although some parts and some fuel did. Both aircraft buried themselves into the buildings' interiors. On the basis of this fact, it is estimated that the impact time was about 0.4 second. This amount of time is consistent with the length of the aircraft (159 feet), the average speed during impact (~389 fps), and the depth dimensions of the building.

With respect to the aircraft impacts themselves, both the North and South Towers performed admirably. Both towers absorbed remarkable amounts of impact energy, sustained significant structural damage, and endured significant applied forces and moments and still stood upright and did not collapse. What the two towers could not endure was the ensuing fire.

Upon impact, both aircraft were wholly destroyed as they penetrated into the towers; consequently, both aircraft released all of their fuel into the interior of the buildings. Since both aircraft had just taken off and both were bound for the West Coast, both had nearly full fuel tanks. The impact to the North Tower was spread over six floors and the impact to the South Tower was spread over nine floors. If 19,000 gallons of jet fuel are spread evenly over nine floors, each with an area of about 40,000 square feet, this amounts to 0.067 gallons for every square foot, or 9 ounces of jet airplane fuel for every square foot of space. This is a significant **fire load** per square foot. Because both planes had flown for a while, the actual amount would have been somewhat less.

The adiabatic flame temperature of jet fuel is about 3140°F, give or take a few degrees depending on fuel additives. The adiabatic flame temperature of a fuel is a theoretical calculation of the maximum temperature at which a fuel burns. Even in the laboratory, flame temperatures do not reach this temperature because of chemical disassociation effects at high temperatures that tend to cool the burning process slightly. Actual flame temperatures in an uncontrolled building interior environment, such as the interior of one of the WTC towers, were likely several hundred degrees less than the theoretical adiabatic flame temperature.

Structural steel loses approximately half of its tensile strength at 1000°F. At 1300°F and higher, it loses most of its strength and stiffness and ceases to be a viable structural component. Likewise, steel-reinforced concrete degrades and cracks at temperatures of 1200°F or more. After the fire initiated, temperatures built up significantly within the building interiors. With jet fuel as the initial primary fire load, temperatures in excess of 1300°F certainly occurred within the impact areas. As the temperature increased, the strength of structural components within the fire-affected areas diminished. When the temperature of the structural components approached and perhaps exceeded 1200°F, the components could no longer carry their loads and failed.

Because the second impact was spread between the 75th and 84th floors of the South Tower, the remaining columns, connections, and supports in the area of the second impact were supporting about 19 floors' worth of weight above the damaged area. Similarly, because the first impact was spread between the 90th and 96th floors of the North Tower, the remaining columns, connections, and supports in the area of the first impact were supporting only about 14 floors' worth of weight above the damaged area. As fire in the area of impact increased the temperature of the structural components located there, those components that carried proportionally more load failed first. This is why the South Tower collapsed after 57 minutes of burn time and the North Tower collapsed after 102 minutes of burn time.

When collapse of the South Tower was initiated, all the floors above the impact area dropped onto the floor just below where failure was initiated. Thus, one floor was called upon to hold the weight of the 19 or so floors above it. Because one average story weighed perhaps 9 million pounds, 19 stories weighed about 236 million pounds. Dropping this group of floors one story converts all the potential energy of this mass at a height of one story into impact kinetic energy. A one-story drop of 19 stories, as a group, is about 2,940,000,000 foot pounds force of energy. This amount of kinetic energy, by itself, is about equal to 80% of that imparted by the aircraft at impact and was more than sufficient to initiate collapse of that floor onto the next lower one, and so on, until the building “pancaked” into a heap. This is also a type of domino effect.

This is the principle that building demolition experts use when buildings are deliberately brought down using explosives. Small explosive charges are used to take out well-chosen structural members so that the resulting falling mass from an upper portion of the building drops onto and crushes a lower portion of the building, which in turn falls upon even lower portions of the building. It is a sort of controlled avalanche. In a sense, the inherent potential energy of the building due to gravity is harnessed to destroy itself.

The North Tower collapsed in a similar fashion to the South Tower. Because the columns, connections, and supports held significantly less weight in the area where the first aircraft impact occurred—14 stories instead of 19 stories—the columns, connections, and supports in the North Tower had to weaken more before failure occurred. The fire had to heat things up to a higher temperature, and this took more time. When the columns, connections, and supports in the impact area of the North Tower weakened sufficiently, the upper 14 or so floors dropped onto the next lower floor and imparted about 1,583,000,000 foot pounds force of kinetic energy to it. Because the single floor could not hold that amount of weight or absorb that amount of kinetic energy without sustaining significant structural damage, it collapsed onto the next lower floor, and so on until it had also “pancaked” into a heap (Figure 18.9).

The collapse of the two towers occurred half an hour apart. Some have presumed that the collapse of one tower somehow precipitated the collapse of the other—that one tower somehow dragged the other one down or shook the other one down. The 29-minute difference between collapses argues that this was not the case (Figure 18.10).

***Figure 18.9*** View of the World Trade Center after collapse. Note the exterior outer support columns, which are about the only structural components still standing. (Courtesy of Michael Rieger, Federal Emergency Management Agency, Washington, DC.)

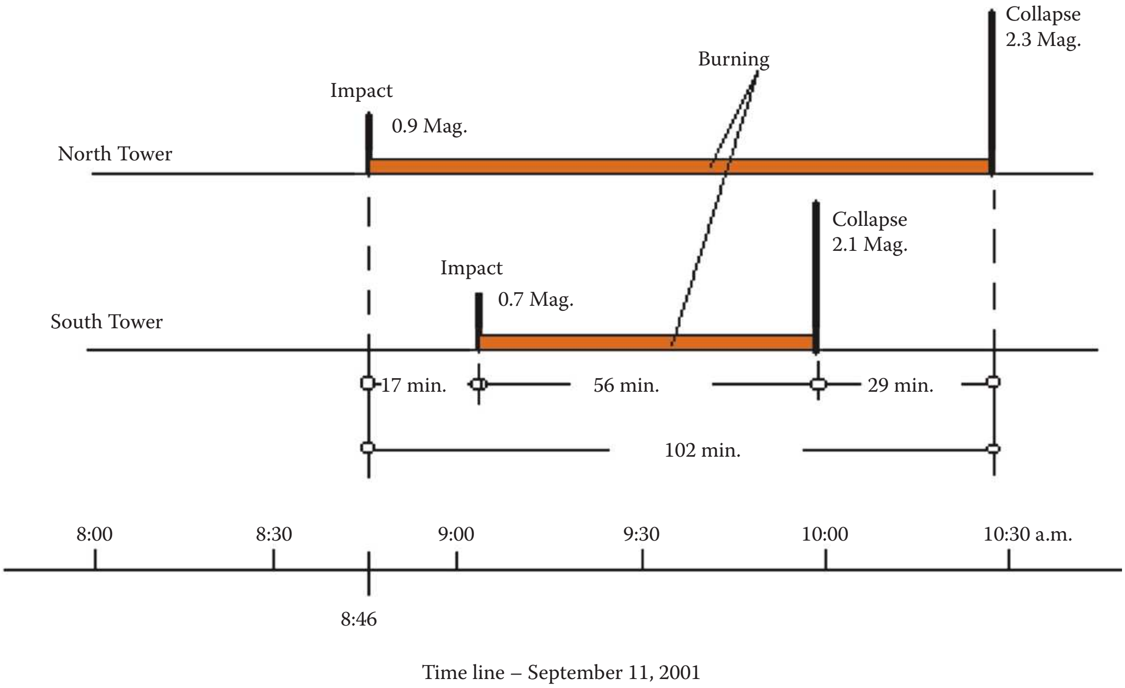



***Figure 18.10*** Comparison of North Tower and South Tower timelines.

What occurred on September 11, 2001, caused many engineers, architects, and planners to consider whether building codes for skyscrapers should incorporate defensive measures and, some have even suggested, offensive measures to deal with the possibility of airplane crashes and other direct acts of sabotage. Some defensive architectural measures were evaluated and incorporated into some types of buildings after the April 19, 1995, Murrah Federal Building bombing event in Oklahoma City where 168 people were killed. Likewise, the U.S. Embassy bombing attack in Lebanon in 1983 that killed 60 people and the bombing of the U.S. Embassy in Kenya in 1998 where 212 were killed and perhaps 4000 were injured have caused people to think more defensively about building design. The topic of deliberate or accidental airplane impact, however, is still being debated. As the public memory of the event has somewhat faded, a new structure, construction of a new One World Trade Center ("Freedom Tower") is nearing completion at the site of collapse.

## Chapter Summary

Forensic engineering is all about energy—tracing it, calculating it, and determining what effects energy has on objects, structures, and people. The fundamental underlying relationship is the first law of thermodynamics, that energy is conserved. Energy may be converted to many different types of energy (heat, kinetic energy, friction, etc.) but it is neither created nor destroyed. Forensic engineers work with these and other fundamental relationships to understand and recreate accidents as well as develop ways to avoid them or minimize destruction when they do occur.

## 18.6 Review Material: Key Concepts and Questions

### 18.6.1 Key Terms and Concepts

Accident avoidance strategy
Accident reconstructions
Bending fracture
Conservation of energy
Conservation of momentum
Dead loads
Debris method
Domino effect
Durometer
Dynamic loads
Elastic collision
Fatigue-type fracture
Fire load
Heat-affected zone (HAZ)
Hooke's law
Irreversible work
Live loads
Margin of safety
Material fatigue
Momentum
Plastic collision
Point of impact (POI)
Shear fracture
Skid formula
Skidding
Static loads
Tensile fracture
VIN (vehicle identification number)

### 18.6.2 Review Questions

1. The death rate in automobile accidents has been halved in almost three decades. How was this done?
2. A car skidded on a roadway that has a coefficient of friction with the road of 0.7. A police officer measured the skid marks and noted them to be 100 feet long. Two years later at a trial, the lawyer for the driver argues that the officer did not measure the skid marks correctly. He asserts, based on photographs, that the skid marks were no more than 92 feet long. Is the difference significant?
3. Improper driving is consistently responsible for approximately two-thirds of all vehicular accidents. What are the three primary categories of improper driving that cause accidents?
4. If improper driving is responsible for approximately two-thirds of all vehicular accidents, what is responsible for the other one-third?
5. What are the two most important analytical tools that an engineer uses to evaluate a vehicular accident?
6. In analyzing a vehicular accident, reliance on verifiable physical evidence should be primary. Give examples of verifiable physical evidence.
7. In vehicular accident cases, eyewitness testimony is usually gathered and recorded. Explain why this type of evidence should be evaluated with caution.
8. Alcohol decreases in a man's blood at a rate of about 0.017% per hour. Bill has an accident, and his blood alcohol level is checked about two hours after the accident at a local hospital. During that time he is in police custody and does not drink anything. The analysis determines that his blood alcohol at the time of testing is 0.05%. If the legal limit is 0.08%, was he legally drunk at the time of the accident?
9. Alcohol decreases in a woman's blood at a rate of about 0.015% per hour. Susan has been drinking and has a blood alcohol level of 0.10%, as determined by a breath analyzer administered by a barkeeper. Being a responsible driver, Susan does not want to drive while legally drunk. How long does she have to wait to have a blood alcohol of less than 0.08%?

10. A car reportedly traveling at 70 mph is struck by another vehicle and immediately begins leaking radiator fluid. The spot where radiator fluid is first noted on the highway is called the point of impact by the officer at the scene. Prepare a scientific case explaining why this is a bogus call by the officer.
11. What is the difference between the dead load and the live load of a building?
12. What are dynamic loads in a building?
13. What caused the Tacoma Narrows Bridge to collapse?
14. When the WTC was designed, what kind of possible aircraft accident was envisioned?
15. If a Boeing 707 instead of a Boeing 767 had struck a WTC tower under the conditions assumed for an accidental impact during take-off, how would its kinetic energy compare to that of the aircraft that struck it on September 11, 2001?
16. Did the impacts of the aircraft into the two towers of the WTC directly cause the towers to collapse? Why or why not?
17. What happens to steel when it is heated in an intense fire?
18. How do demolition experts use small explosive charges to collapse large buildings deliberately?

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# 19
# Forensic Computing


## Chapter Overview

Forensic computing may fairly be called the newest forensic discipline, and in some sense it is a logical extension of questioned documents. Here, the documents exist in computers and on disc drives, memory chips, and other storage devices for thousands of devices. Evidence is evidence, be it electronic or physical. In this chapter, we will examine the status and role of forensic computing, as well as the procedures used.

# Chapter 19
# Forensic Computing*

*Zeno Geradts and Thomas A. Johnson*

## Chapter Outline



## 19.1 Crime Scenes with Digital and Electronic Evidence

The electronic crime scene with digital and **electronic evidence (digital evidence)** poses new challenges for the investigator that are quite different from what we have discussed regarding traditional crime scenes such as homicides. This new environment is unique not only because the evidence may be difficult to detect but also because of how its evidentiary value may be hidden through steganography and encryption. Furthermore, there is a degree of anonymity in which perpetrators can hide their true identity in the forging of certain criminal acts and endeavors. Therefore, the rapid technological advancements occurring in our society through the digitalization of data and information are presenting new challenges

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* This chapter is based on Chapter 27, "Informatics in Forensic Science," by Zeno Geradts, and Chapter 28, "Computer Crime and Electronic Crime Scene," by Thomas A. Johnson, as published in the third edition of this text.

**SIDEBAR 19.1. CAREER PREPARATION AND EXPECTATIONS**

Forensic computing is similar to forensic engineering in that those who work in the field are not usually associated with a forensic laboratory in the traditional sense. However, in contrast to forensic engineering, there are degree programs specifically for forensic computing, and a curriculum in digital evidence analysis can be accredited through the Forensic Education Programs Accreditation Commission (FEPAC, http://www.aafs.org/fepac). Forensic computing specialists can work in law enforcement agencies as well as in private consulting.

to investigators. This electronic evidence is both difficult to detect and quite fragile; therefore, the latent nature of electronic evidence requires very skilled investigators. (For a discussion of career preparation for this field, see Sidebar 19.1.)

Challenges that confront the investigator encountering an electronic crime scene center on the global nature of the evidence. In many criminal cases involving computers and electronic technology, we encounter multijurisdictional issues that challenge the very legal structure of all nations' legal and statutory codes. For example, today we find criminal enterprises being initiated from various nations throughout the world, and to effectively investigate, apprehend, prosecute, and convict these individuals we must utilize appropriate judicial search warrants. It is also necessary that the penal codes of the respective nations have statutory authority for legal action to be pursued.

An additional problem with this criminal activity, which relies on technology and electronics, is the ease with which one person can impersonate another through elaborate spoofing schemes. A related activity that has cost our nation's businesses enormous financial losses is identity theft. It generally takes victims of identity theft approximately 6 to 9 months of work with credit agencies, bill collectors, and other credit entities before they can begin restoring their good name and credit standing.

Because personal computers can store the equivalent of several million pages of information, and networks can store many times more this amount of data, the location and recovery of evidence by a trained computer forensic specialist working in a forensic laboratory may take several days or weeks. As mentioned earlier, searching computer files is an extraordinarily difficult process, because files can be moved from one computer to another throughout the world in a matter of milliseconds. Files can also be hidden in slack space of the computer hard drive or stored on a remote server located in other geographic jurisdictions. Files can also be encrypted, misleadingly titled, or commingled with thousands of unrelated, innocuous, or statutorily protected files.

## 19.2 Computers, Electronic Equipment, Devices, and Information Repositories

Both first responders to crime scenes and investigative personnel must appreciate the unique attributes of electronic equipment and be prepared to identify and assess its importance at a crime scene. This suggests that the types and purposes of electronic equipment should be well understood as to their functionality and value to their owner. Also, from the viewpoint of assessing the potential impact on the victim, a thorough knowledge of this new environment will prove most useful and beneficial to law enforcement because the crime scene must be protected and processed in accordance with forensic science principles. Because electronic evidence is so fragile, we must train officers in the preservation and collection of electronic evidentiary materials. Digital evidence can easily go unrecognized, or be lost, if not properly processed. We must also ensure the integrity of digital evidence, because it is easily alterable. For these reasons, training first responding officers to electronic crime scenes is an extremely critical function and one that must be addressed by state and local law enforcement agencies throughout our nation. Today, given the ubiquitous presence of computers, answering machines, smart phones, facsimile machines, and other electronic equipment, almost any crime scene may conceal information of value in a digital format. The acquisition of this information is totally dependent on the actions of the first responding officer, who must have the ability to visualize and perceive the presence of such evidentiary material.

### *19.2.1 Value of Equipment and Information*

The type of computer system or electronic environment the investigator may encounter at a crime scene has a certain tangible and intangible value to the owner, victim, suspect, or witness. Because this value is measured not only in financial terms but also in terms of informational value, there are numerous perspectives that the investigator must be prepared to analyze. It is possible that the owner of a computer system may have become a victim or may become a suspect in a case involving criminal activity. A computer system can be the target of criminal activity or it can be an instrument used to commit criminal activity. Data residing on the hard drive can be used to determine which is the case. More often than not, the information that resides within these computer and electronic systems is of greater value than the systems themselves. The proliferation of new technologies at extremely economical prices will continue to make the investigator's job more difficult. We are now in an era where computer communications can occur by using a RAM cache, thus avoiding writing to the hard drive, and this can occur in a networked environment from any point to any other point. Also, the development of encrypted hard drives will make the investigator's job both more difficult and more expensive.

### *19.2.2 Information Collection*

The investigator may look for information on a suspect or criminal by searching for electronic data that may reside in four specific locations:

1. Computer hard drive
2. File servers (computer)
3. Databases from governmental agencies, as well as private and corporate databases
4. Electronic record systems from governmental to private and commercial sectors

The first responding officers to a crime scene in which electronic equipment is present must recognize the presence and potential value of this electronic equipment. They also must provide the necessary security to ensure protection of potential evidence located on hard drives and file servers as the case moves from a preliminary investigation to a full investigation.

The searching and seizure of computer hard drives for information must be done within the parameters of a lawful search either incident to arrest or with appropriate judicial search warrants, or both. The investigator performing the search of a computer hard drive must be sufficiently trained and educated in the use of appropriate software utilities used in scanning hard drives. Furthermore, the officer must use the department's approved protocol for conducting such a search. This includes creating a disk image on which to perform the search of the targeted hard drive while maintaining the integrity of the original hard drive and ensuring that none of the data residing on the hard drive are modified by the software utilized to search for appropriate information. The imaged hard drive should also be duplicated for eventual defense motions regarding discovery of the data, in the event the defense counsel wishes their forensic computer experts to review or perform independent analysis of the hard drive.

Information on individuals, whether they are suspects, victims, or individuals of particular interest, can be obtained through a wide array of governmental and private electronic record systems. Financial reports and credit histories contain a vast storehouse of data not only on the individual in question but also on spouses, relatives, and friends. Because law enforcement agencies also have the responsibility of protecting the privacy of individuals, great care must be exercised in searching the enormous range of databases that now exist within our society. This implies that legal rules must be vigorously adhered to through the use of subpoenas and application for judicial review or search warrants.

### *19.2.3 Management of the Electronic Crime Scene*

Managing an electronic crime scene is quite similar to managing any other crime scene, with the exception that specific skills and training will be required of the forensic computer investigator. In addition, the type of crime committed will invariably call for an exceptional team effort by the seasoned crime investigator in cooperating with the electronic crime scene investigator. Because most police organizations do not have adequate resources to fully staff their departments with individuals who possess such demanding skill attributes, it is not uncommon to find that regional task forces have been developed to address these issues. However, this can lead to complications regarding jurisdictional issues, command and control, collection of evidence, and sharing of information with other members of the crime scene team. Because most electronic crime scenes are photo-rich environments, all of the traditional crime scene mapping, photographing, and diagramming are essential to the proper investigation. The crime scene may contain computers that may have to be searched not only for information residing on their hard drive but also for fingerprints and DNA from the keyboard, diskettes, and other areas of the computer. Therefore, a protocol for addressing such issues must be planned beforehand and made available to all personnel, should implementation of such requirements become necessary.

### *19.2.4 Electronic Crime Scene Procedures*

The variety of electronic devices and potential electronic evidence evolves as quickly as the technology. For example, ten years ago, cell phones were relatively rare while personal data assistants (PDAs) were relatively common. Music players are nearly ubiquitous as are global positioning system (GPS) devices or devices that incorporate GPS capability. Digital cameras are standard in cell phones and PDAs are becoming rare, also being replaced by cell phones. Tablet computers are rapidly emerging as a significant source of digital evidence. A crime scene with electronic evidence is treated as any other scene as far as general procedures are concerned (Chapter 3). Once the scene is secure, the crime scene investigator has additional tasks associated with the protection, documentation, and collection of electronic evidence. Many of these procedures are unique to electronic evidence and include the following:

1. Protect the evidence and, if people are at the scene, do not permit anyone to touch any computers or other electronic instruments. All connectivity, including wireless and Bluetooth, should be disabled if possible.
2. Note if a computer is on or off. If it is on, the screen should be photographed as found. All wires and cords connecting various devices should be labeled to allow for reconstructing the exact configuration once the devices are removed from the computer. The computer could be configured to overwrite data; therefore, for standalone computers, it is best to remove the power plug from the wall. It is important when authorities encounter a network as opposed to a standalone computer that no one remove the power cord from the server. If the agency does not have personnel who are trained to work in a network environment, other assistance should be requested.
3. If a crime scene will require the use of fingerprinting powders to develop potential latent prints on the computers, inform the crime scene supervisor that no aluminum-based powders should be used to dust for fingerprints on the computer, because they could create electrical interference. In fact, forensic processing of the computer and its hard drive should occur prior to any dusting for fingerprints. The forensic computer investigator or the person who will actually process the computer should then take care not to preclude a subsequent search for traces of DNA evidence and an examination for latent fingerprints.
4. Transport computers and other electronic instruments and evidence with caution so as not to damage or lose the fragile electronic data. It is advisable not to transport this equipment in the trunk of a police car because this is the area where the police unit's two-way radio is located, and the signals may damage the data stored in the computer and other electronic instruments.
5. Store and maintain computers and electronic equipment in an environment that is conducive to preserving the data contained in that equipment and is free from any nearby magnetic fields.

In those cases where the forensic computer investigator may participate as a member of a raiding team, there will obviously be time to prepare and plan for appropriate action, as opposed to being called to a crime scene as a result of the first responding officer's request for assistance. In the case of a preplanned raid, the forensic computer investigator will clearly be aware of the criminal activity and will have the opportunity to engage in pre-search intelligence. This will permit the opportunity to engage skilled personnel who will be able to process the scene on arrival. The presence of a network may be determined, and appropriate plans can be developed for processing this environment. Also, it may be possible to gather useful information about the situation from the **Internet service provider (ISP)**. In short, knowledge about the location, equipment, type of criminal activity, and other pertinent facts will enable the forensic computer investigator to assist the prosecuting attorneys in the preparation of search and seizure warrants. Also, involvement as a member of the raiding team will permit developing a more tailored plan in which minimal loss of data to the computer and electronic environment will occur.

## 19.3 Initiating the Forensic Computer Investigation

Once a forensic computer investigator is called on to initiate a formal assessment of a case involving a computer—as an instrument of crime, as a repository of data or information associated with a crime, or as a target of a criminal act—it will be necessary for the forensic computer investigator to prepare an investigative protocol to correctly gather and preserve any appropriate evidentiary material.

In the collection of evidence from a computer hard drive, it is important to make a bitstream copy of the original storage medium and an exact duplicate copy of the original disk. After the evidence has been retrieved and copied, the **bitstream data copy** of the original disk should be copied to a working copy of the disk so that the analysis of the data will not contaminate the evidence. In the analysis of the digital evidence, you may have to recover data, especially if the users have deleted files or overwritten them. Depending on the type of operating system being used by the suspect, the computer investigator will determine the nature of the forensic computer tools that will be applied. For example, when examining Windows®, Macintosh®, or LINUX systems, one has to understand the file systems that determine how data are stored on the disk. When accessing a suspect's computer and inspecting the data, it will be necessary to have an appreciation and working knowledge of the aspects of each operating system. For example, Microsoft® Windows® and Apple® software are quite different and the investigator must understand these differences. Additional information on initiating a forensic computer investigation will be provided in greater detail in subsequent chapters of this text. In the interim, a brief taxonomy of crimes impacting the forensic computer investigator may be useful to review:

*The computer as an instrument in criminal activity*

- Child pornography and solicitation
- Stalking and harassment
- Fraud
- Software piracy
- Gambling
- Drugs
- Unauthorized access into other computer systems
- Denial-of-service attacks
- Data modification
- Embezzlement
- Identity theft
- Credit card theft
- Theft of trade secrets and intellectual property
- Extortion
- Terrorism

*The computer as a target of criminal activity*

- Theft
- Virus attack
- Malicious code
- Unauthorized access
- Data modification

- Intellectual property and trade secrets
- Espionage to government computer systems
- The computer as a repository of criminal evidence
- Child pornography and child exploitation materials
- Stalking
- Unauthorized access into other computer systems
- Fraud
- Software piracy
- Gambling
- Drugs
- Terrorism-attack plans
- Terrorist organizations' website recruiting plans
- Credit card numbers in fraud cases
- Trade secrets
- Governmental classified documents as a result of espionage activities

## 19.4 Other Applications of Computers and Related Technology to Forensic Science

Image analysis, recognition, and evaluation are fast becoming important tools supporting forensic investigations as well as in homeland security and terrorist investigations. All of these tasks involve the use of sophisticated software, ranging from the familiar Adobe® Photoshop® to specialized packages. This software is used to examine photographs, videos, and digital images of all types from cell phone pictures to satellite imagery.

### *19.4.1 Video Image Processing and Animation Software*

Because of the number of installed camera surveillance systems, it is common for a crime to be recorded on a **closed-circuit television (CCTV)** system. If this occurs, the CCTV images can be used as evidence in court. The court often asks for image processing to get a clearer image of the video and for comparison of the video images with a suspect. Furthermore, the court sometimes asks if an image has been manipulated. In the past, the systems were analog, but since the move to digital systems, where files are stored on a hard disk, the number of CCTV systems on videotapes is declining rapidly.

### *19.4.2 Image Enhancement*

Surveillance video images often are of poor quality. This is caused by light conditions, the resolution of the system, and videotape wear. In practice, it is rare for image processing (apart from contrast stretching) to improve the quality with these kinds of images on a single image. Figure 19.1 shows an example of a surveillance image. In this image, there were questions as to whether to visualize the number plates and thus identify the persons or to magnify the faces. It is important to validate the methods before giving the results to court.

***Figure 19.1*** Example of a surveillance image.

### 19.4.3 Surveillance Systems

In the past, time-lapse videotapes were submitted to the laboratory. Today, digital systems are far more common, but they are often of lower quality, depending on the settings. Because there are no standards yet for digital systems, they can be difficult to handle at the forensic laboratory. Often, the system itself should be seen before the optimal images are acquired. Digital systems can be a hard disk with JPEG compressed images, MPEG streams, or digital tapes. Often, the format of storage is proprietary on the hard disks, and there is no standardization in this field yet. These systems have many options for the operators, where the number of images per second and different actions for the alarms can be set. It is important to have a database of players to view the different formats.

### 19.4.4 Noise Removal

Many types of noise exist in a surveillance system; however, because the types of noise are distinguished for the video system if noise is introduced by playing and digitization, it might be worthwhile to play the recording more often and average the final result. One danger with this method is that the tape can be damaged if it is played too often. Averaging over multiple frames can also reduce the noise. This can be valuable if there is a night recording with a scene that does not move. One problem is that if people move, they are not visible anymore. The value of this method depends on the part of the image that has to be visualized.

### 19.4.5 Three-Dimensional Reconstruction

There are several approaches to comparing a suspect with a video image. One is to bring the suspect to the same video recording system and ask the individual to stand in the same position as the people visible on the video recording. The problem with this approach is that the place must still be available (often, it might be necessary to rebuild the place or shop owners may not cooperate) and the suspect must cooperate as well. Furthermore, there should be people available who look similar to the suspect so one can draw conclusions about the uniqueness of the suspect's features.

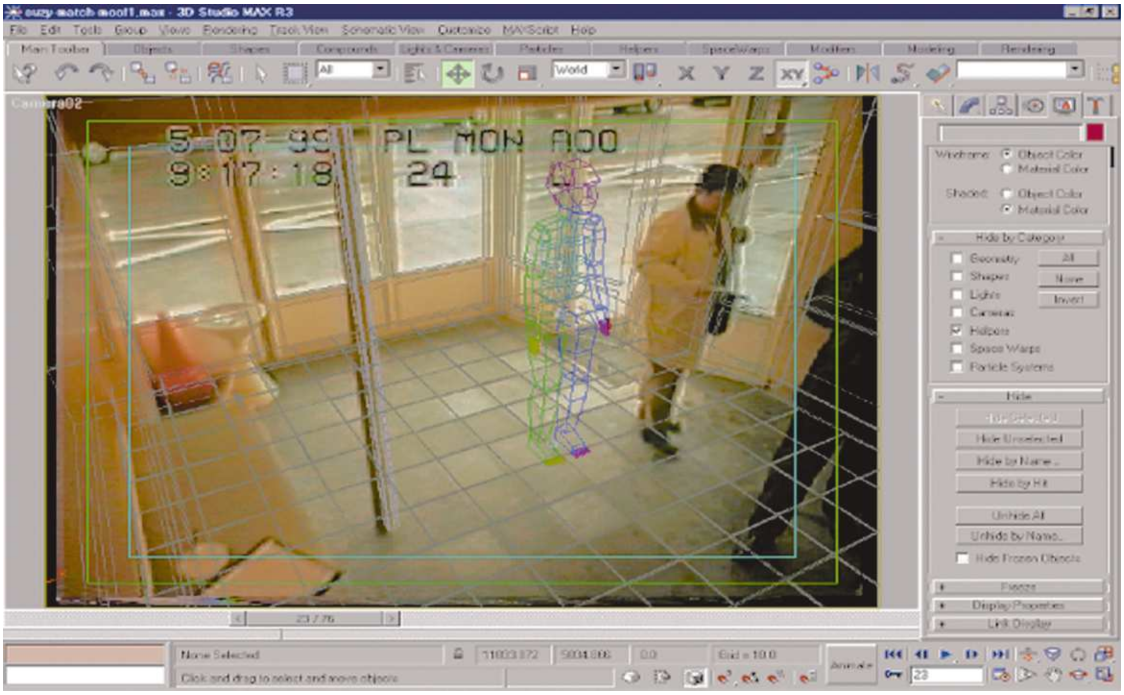


***Figure 19.2*** Example of human model in three dimensions.

The other method is **photogrammetry**, which requires many parts of the scene to be measured to determine the height and size of suspects. Commercially available human modeling software packages can be used to determine the size of persons in a video image. Figure 19.2 shows an example of such software (3D Studio MAX). It can be difficult, however to accurately determine size because there might be errors in the measurements or there might not be enough reference points in the image. Furthermore, if someone is bent over, it is not known how much that height differs from the full height, and the influence of shoe heel height and head size must be taken into account. For this reason, although such three-dimensional images appeal to people's imaginations, these kinds of models should be validated for each image before they can be used in court; otherwise, the evidence may not be accepted.

### 19.4.6 *Image Integrity*

Images can be manipulated. Compared to other evidence (e.g., DNA, fingerprints), the question arises more often as to whether the images have been tampered with. Analog videotapes can be examined and declared to seem to be original. It may not be possible to determine whether or not the videotape has been altered professionally. A stronger type of evidence is available with cameras. If the question arises whether a camera has recorded a video image or a still image, there might be information in the image itself. One of the strongest kinds of evidence is pixel defects in a camera, the number of which can be used to identify a camera. An example is shown in Figure 19.3. Cameras might hide serial numbers in files or by stenography, an approach that is currently being researched. For this reason, digital systems might provide good methods for authentication.

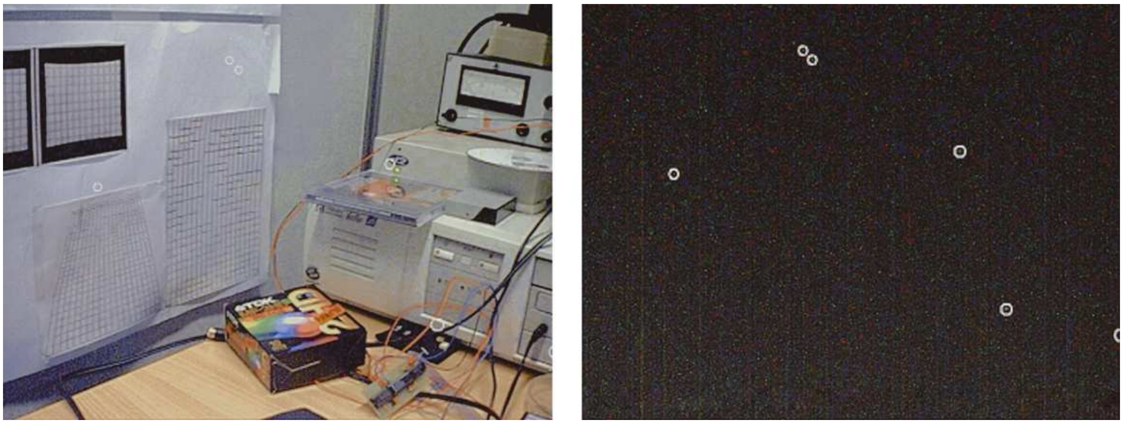

***Figure 19.3*** Camera identification based on pixel defects.

## Chapter Summary

This chapter has provided an introduction to the paradigm change that is occurring with reference to crime: Today's criminals are using computers as their tools to take advantage of new technological possibilities. The forensic computer investigator has to be prepared to investigate criminal acts in which the computer may be a target of the criminal. This implies that individual, corporate, and government computers are at risk as targets of opportunity. The data residing in these computers have value and are subject to loss, in some cases at enormous expense; therefore, the forensic computer investigator must be cognizant of this environment and how to develop systematic plans for investigating those who use computers and sophisticated electronic equipment in the commission of criminal acts. The computer can serve as a rich repository of data regarding the fruits of criminal activity, or evidence regarding its use to attack or harm another individual, corporation, or government can be revealed. The categorization of an electronic crime scene full of new technologies that store data and information of potential evidentiary value suggests that we must educate our law enforcement officers to recognize characteristics of this new environment so that they can function effectively in it.

## 19.5 Review Material: Key Concepts and Questions

### *19.5.1 Key Terms and Concepts*

Bitstream data copy
Closed-circuit television (CCTV)
Digital evidence
Electronic evidence
Internet service provider (ISP)
Photogrammetry

### 19.5.2 Review Questions

1. What are the major challenges investigators confront with digital and electronic evidence in the new electronic crime scenes?
2. It is generally accepted as good police practice that, when entering an electronic crime scene, the investigator should follow certain guidelines; identify and discuss these guidelines.
3. Computer crime cases involve a level of complexity that requires the investigator to possess knowledge of both legal requirements and procedural requirements for effecting search and seizure of evidentiary material. Identify the most common mistakes made by the investigator.
4. Describe how the forensic computer investigator collects evidence from a hard drive.
5. Why should a bitstream copy of the original storage medium and an exact duplicate copy of the original disk be made?
6. In the analysis of digital evidence, is it possible to recover deleted files? If so, describe the process one would have to consider using.
7. Identify the typical cases with which investigators will be involved when the computer is used as an instrument in criminal activity.
8. When the computer is a target of criminal activity, what types of cases is the investigator most likely to encounter?
9. Which precautions should be taken for 3D reconstructions?
10. Discuss the process of photogrammetry.

## 19.6 References and Further Reading

### 19.6.1 Books

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# Section VIII Summary

This section describes disciplines that are not usually practiced in the traditional forensic laboratory as we have described in earlier chapters. Those working in forensic engineering or forensic computing quite often work outside of laboratories and as consultants, although, as digital technologies are becoming more embedded in our lives (e.g., cell phones, GPS units, iPod®s), digital evidence may well become as common and as important as physical evidence.

## Integrative Questions

1. Forensic engineering is sometimes referred to as forensic physics. What other forensic disciplines integrate physics and how?
2. How does the imaging discussed in this chapter tie in with documentation of crime scenes as described in Chapter 3?
3. List types of digital evidence that you would expect to find at a homicide scene occurring in someone's home?
4. How is digital evidence fundamentally different from physical evidence such as a fiber or a bloodstain?
5. What do forensic engineering and crime scene reconstruction have in common? How do they differ?

# SECTION IX

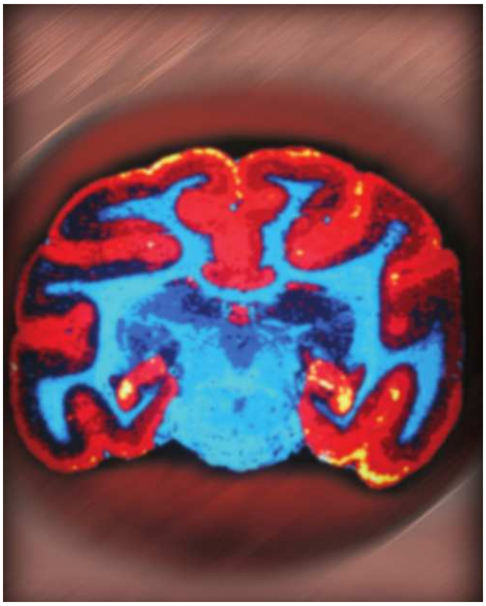
# The Human Element and the Future of Forensic Science


## Section Overview

This final section focuses on human behavior—the ultimate driver of criminal actions. We will learn how behavioral science can assist other forensic sciences and investigators by providing insights into the "why" of crime and other associated behaviors. You have probably heard the term "profiler"; that is part of what is discussed here, although you will learn that profiling is just one of the many different applications of behavioral sciences to forensic science. We will end this section and the book with a brief overview of what the future of forensic science might look like.

# 20

# Behavioral Science and Forensic Science



## Chapter Overview

We have spent most of our time discussing things associated with forensic science such as physical evidence, laboratories, procedures, and practices. We will end the book with a brief introduction into the ultimate reason for the existence of forensic science—human beings and their behavior. The study of human behavior is addressed through the disciplines of psychology and psychiatry. We discussed crime scenes in detail in Section II, Chapters 3 and 4, but we approached it from the perspective of answering questions such as "who?" and "how?" Now we will delve into why, but with the recognition that the answer to the question "why?" is often unknowable. However, there are patterns and consistencies that can be useful to law enforcement, forensic science, and the judicial system.

Key applications of behavior science in forensic sciences include determination of competency (i.e., whether or not a person is competent to stand trial or represent themselves), determination of truthfulness (identification of deception), identification of genuine mental illness and uncovering faking or malingering, determination of sanity, and performance of **psychological autopsies**. The latter would be important in cases where there is a question as to whether a person committed suicide by purposefully wrecking their car, for example, rather than dying accidentally. This is part of the study of equivocal death. In such cases, the question is not the cause of death so much as the manner of death, both of which were discussed in Section III.

The behavior sciences are central to criminal profiling and are utilized to try to reconstruct an offender's behavior and motivations based on an analysis of a crime scene. As used here, profiling arises from the assumption that how a person acts helps to define who a person is, to form their personality. Thus, behavior reflects personality, whether a person is sitting at home watching television, studying in a classroom, or committing a violent crime. This axiom applies at crime scenes as well.

# Chapter 20

# Behavioral Science and Forensic Science*

*Kenneth P. Baker, Robert D. Keppel, Michael R. Napier, Robert L. Sadoff, and Louis B. Schlesinger*

## Chapter Outline



## 20.1 History and Development

The history of forensic psychiatry in the United States is entwined with general psychiatry and inpatient psychiatry in institutions and asylums, especially during the 19th and 20th centuries. Forensic psychiatry came into its own in America when Isaac Ray published his *Treatise on the Medical Jurisprudence of Insanity* in

* This chapter is based on Chapter 29, "Forensic Psychology," by Louis B. Schlensinger; Chapter 30, "Forensic Psychiatry," by Robert L. Sadoff; Chapter 31, "Serial Offenders: Linking Cases by Modus Operandi and Signature," by Robert D. Keppel; and Chapter 32, "Criminal Personality Profiling," by Michael R. Napier and Kenneth P. Baker, as published in the third edition of this text. Portions of this chapter were adapted with permission from Schlesinger, L.B., Ed., *Serial Offenders: Current Thought, Recent Findings*, CRC Press, Boca Raton, FL, 2001.

Boston in 1838. Ray influenced a number of judges and others in criminal cases and also set standards for treatment in his hospital in Rhode Island. Forensic psychiatry proliferated in about the mid-20th century when the general revolution in psychiatry in the United States occurred, primarily in the 1960s and 1970s. Major changes in criminal law and insanity encouraged the use of psychiatrists in various aspects of the criminal justice system.

Forensic psychiatrists began training one another through fellowship programs at various universities and, in 1968, several individuals got together at an American Psychiatric Association meeting in Boston to share their knowledge. Out of this group emerged the American Academy of Psychiatry and the Law (AAPL, http://www.aapl.org), the first meeting of which was held in October 1969. Eight individuals attended that first meeting; currently, there are more than 2200 members. AAPL has maintained its high level of educational function through annual meetings, board review courses, and committee structure to help the continuing education of forensic psychiatrists.

Board certification in forensic psychiatry occurred through the American Board of Forensic Psychiatry (ABFP, http://www.abfp.com), spearheaded by AAPL and the American Academy of Forensic Sciences (AAFS) in the early 1970s. More than 200 individuals were board certified by the ABFP until it was concluded in 1994, at which time the American Psychiatric Association (APA) and the American Board of Psychiatry and Neurology assumed the function of accrediting and certifying forensic psychiatrists. The new certification is time limited to 10 years, at which time a new examination must be passed for the individual to remain certified.

Training programs in forensic psychiatry have also proliferated to the point where there are now over 25 accredited programs in the United States. At present, an individual wishing to be certified in forensic psychiatry must take a 1-year accredited program of training in forensic psychiatry. Correctional psychiatry (mental health professionals working within the corrections system) is also included in the training to become a forensic psychiatrist; however, the profession branches to either correctional or forensic psychiatry once the training is completed. Most individuals working in correctional psychiatry do not do forensic work but have a general psychiatric practice or are full time in corrections. Most individuals working primarily in forensic practice do not have correctional appointments. Additional information on career preparation is given in Sidebar 20.1.

Forensic psychology emerged later, to some extent building on the legal acceptance of forensic psychiatry. Prior to the 1970s, most forensic evaluations requiring court testimony were provided by psychiatrists rather than psychologists. Clinical psychology, which only began after World War II, did not gain licensure as an independent profession in all states until the late 1970s. Accordingly, the only way a psychologist could become involved in a forensic case, as an independent private practitioner, was under the auspices of a psychiatrist. Occasionally, psychologists were called on to testify in court, but usually the testimony was limited to the results of **psychological testing**. Psychologists had not yet gained public acceptance as members of an independent profession and, therefore, were not permitted to consider specific **psycholegal** issues such as competency or criminal responsibility; these were considered medical issues, under the sole purview of psychiatry.

In several legal cases, beginning with *People v. Hawthorne* (1940), courts were asked to decide whether psychologists should be allowed to give testimony. In *Hawthorne*, the court held that there was "no magic of an MD degree" and allowed properly trained psychologists to testify about a defendant's mental state. In a similarly decided civil case (*Hidden v. Mutual Life*, 1957), the court also permitted psychologists to testify.

**SIDEBAR 20.1. CAREER PREPARATION AND EXPECTATIONS**

In forensic science, the behavioral aspects are dealt with by psychologists and psychiatrists. Both require education and training beyond a typical 4-year college degree. Although often lumped together, forensic psychology and forensic psychiatry have some significant differences. Forensic psychiatrists are medical doctors whose specialty is psychiatry, which focuses on prevention, diagnosis, and treatment of mental illness. This can include addictive and emotional disorders such as schizophrenia and other psychotic disorders, mood disorders, anxiety disorders, substance-related disorders, sexual and gender identity disorders, and adjustment disorders. Unlike a psychologist, a psychiatrist can order diagnostic laboratory tests and prescribe medications to treat mental illness and alleviate symptoms. In general, the forensic psychiatrist is called by attorneys or judges to assess individuals for mental state in the past (legal insanity or testamentary capacity), in the present (competency to stand trial or other forms of present competency), or in the future (prediction of dangerousness). Only the assessment of the current state of competency is based primarily on a present examination of the individual in question. The retrospective and prospective assessments require other materials besides a psychiatric examination such as previous hospitalizations, psychiatric examinations, medical assessments, and other observations of an individual to give testimony "within reasonable medical certainty."

Forensic psychologists are not physicians but often have advanced degrees. They are involved in assessment, treatment, and provision of testimony in a variety of legal cases in areas such as family law (including custody and visitation matters), civil law (personal injury, workers' compensation, wills, and contracts), and criminal law (including the various types of competencies, responsibility, and sentencing). Many psychologists are developing subspecialties in forensic psychology, limiting their practice to one or two types of legal issues such as criminal offenses, sexual harassment, or product liability. In the area of treatment, they provide services to offenders in prisons, in lieu of incarceration, or following release, as well as to the victims of crimes. Behavioral scientists work in both the criminal and civil legal settings.

However, the decision considered landmark is *Jenkins v. United States* (1962), because in this case a federal court allowed psychologists to testify as expert witnesses in criminal matters. Despite these early court decisions, it was not until the 1980s that a psychologist's testimony was used regularly. During this time, laws were enacted that allowed patients to be reimbursed for psychological services by insurance companies. As a result, mental health care, especially health care provided by psychologists, became available to most of the population, whereas previously it had been provided only to the wealthy or to those who went to publicly funded centers. Thus, psychology gained general acceptance by society as an independent mental health profession and psychologists' expertise was increasingly called on by the courts. Many states had to change specific laws, so that instead of allowing forensic examinations to be performed only by psychiatrists they now included licensed psychologists as well.

By the early 1990s, forensic psychology was well on its way to becoming a major participant in legal decision making. At the beginning of the 21st century, an area of practice that had been previously dominated entirely by psychiatry was now beginning to be influenced by psychology. Along the way, forensic psychologists

**CASE STUDY 20.1: THE IMPORTANCE OF EXPERIENCE IN FORENSIC PSYCHOLOGY**

A 38-year-old female (B) with a 20-year history of drug abuse and related offenses (including drug selling and prostitution) rented a room in a boarding house occupied mainly by other drug addicts. There, she met a 42-year-old drug dealer (A) and began a 5-month intimate relationship with him. She continued to sell drugs and became known as A's "enforcer." She carried a gun and frequently intimidated drug buyers by pistol-whipping them or hitting them over the head with a pipe for not paying on time, or for no reason at all.

The victims in this case were two drug users who owed A and B $600. According to numerous witnesses, B urged A to track down the victims, who were then abducted by B and A, taken to the boarding house, and—again at B's instigation—killed. Several people who were in the hallway overheard what was going on because the walls in the boarding house were "paper thin." These witnesses heard the female victim begging B for her life and struggling as B approached her and strangled her. They heard the male victim choking as B shoved newspaper down his throat while A held a gun to his head. They also heard B, who seemed to be enjoying the intimidation and the killings, suggest that she and A should take the bodies to a local field and set them on fire.

A and B were arrested shortly afterward. A refused to give a statement, but B gave four different versions of what occurred, implicating others and finally admitting that she participated, but only as an assistant to A, who she said was the primary actor. Nevertheless, she was charged with murder and sent to jail, where she awaited trial. After B had been in jail for 3 years (her trial delayed by a number of legal maneuvers), her defense attorney retained a psychologist with expertise in the treatment of battered women. The psychologist

established standards for the profession and appointed credentialing bodies, such as the American Board of Forensic Psychology, to certify that practitioners have expertise in this subspecialty (see Case Study 20.1). The path to becoming a forensic psychologist is still typically that of the clinical psychologist, with additional forensic training and experience. Recently, however, several universities have established programs offering doctoral degrees in forensic psychology specifically designed to provide students with a broad background in basic clinical skills and in relevant areas of law and criminal behavior.

## 20.2 Testing Tools

Personality is assumed to dictate behavior that is reflected in evidence left at a crime scene. It is therefore critical to many investigations to explore personality, both of offenders and victims. Psychological testing is a quantitative or quasi-quantitative method of evaluating personality, psychopathology, and mental functioning. For many years, testing has been used to supplement information obtained through clinical interviews and various background records. Testing has always had general appeal because its purpose, in large part, is to reduce the subjectivity of the clinical evaluation, as well as to assess the individual from a different perspective.

began her interview by asking the defendant to describe her relationships with prior boyfriends, including her codefendant. B gave a history typical of battered woman syndrome. During the 3 years that she had been incarcerated, she attended weekly battered woman's workshops (as did all the female inmates), where she heard many lectures on the topic. The psychologist concluded (basing her findings solely on what B told her) that the defendant had battered woman's syndrome, was passive and compliant, had low self-esteem, and killed the victims to prevent herself from being killed by A: "B was intimidated at the time of the murders into helping A, which would be considered reasonable for any person in that situation, even more so for someone who was battered and who was passive and compliant. One can attribute to her the status of being a kidnapping victim or the victim of a terrorist. She was his victim and had to comply in order to save her own life." This expert did not ask B about several witness statements that described her as aggressive, intimidating, and taking the lead role in the murders. She also did not consider B's criminal record, which included a long history of violence, drug selling, prostitution, and several assaults.

When B's case came to trial, the jury concluded that she was responsible for both murders and that the battered woman plea lacked merit. In this case, the defense psychologist was not incompetent or untruthful, but she simply did not know how to conduct a forensic evaluation. She was basically practicing clinical psychology in a forensic setting, approaching the defendant as she would any patient who came to her private office. Although this expert reported that she had read the legal discovery, her conclusions demonstrate that she ignored these findings or, at the very least, believed that her own evaluation of the defendant was more valid. The expert did not help the defendant and did not provide much psychological understanding of her crime.

**Projective tests** are based on the notion that, if an individual is shown an ambiguous stimulus and asked to respond to it, his or her responses will reveal aspects of his or her personality. Inner thoughts, wishes, conflicts, and feelings will be projected onto the ambiguous stimuli, enabling the psychologist to see the subject's inner life. Perhaps the most widely used projective test is the familiar Rorschach inkblot test. In this test, a subject is shown a series of ten inkblots and is asked to describe what he or she sees. Although this test has had its critics, it has sustained continued popularity for decades. It has been used not only in clinical settings but also in forensic contexts, and its scientific validity is generally accepted. The Rorschach's primary use is to assess personality structure, dynamics, presence or absence of a thought disorder, and accuracy of reality testing. Another projective test, the **Thematic Apperception Test (TAT)**, is a simple, widely used and respected projective technique. In this test, a subject is shown a number of pictures depicting various everyday situations and is asked to create a story based on the picture; in the process, it is assumed, he will reveal his wishes, thoughts, conflicts, feelings, and motives.

Although the Rorschach test has value in elucidating personality structure, level of personality integration, and extent of inner cohesiveness, the TAT is often more helpful in uncovering relevant psychodynamics. Its usefulness is demonstrated by the response of a 22-year-old offender who committed a murder following a sexual assault. Some important psychodynamics were revealed through the story he created for one TAT card: "This is a sex crime. A rape crime. He feels sorry. He forced her. She didn't want to do it and he did. He liked the woman. He then kills the woman so she doesn't go and talk to the police. He chokes her. He thought he'd be in jail for rape, so he decided to choke her. He thought she would tell the cops that he raped her. He also killed her because he didn't want his wife and children to know he raped a woman. He doesn't get caught because the police don't have any proof he killed her. He liked killing her, too." In other instances, a subject may recognize the purpose of the TAT and may intentionally create non-revealing stories to conceal his or her inner motives and dynamics. Although such a guarded protocol may not be helpful in uncovering the offender's inner life, it may point out a conscious attempt to conceal what is going on internally, which is also an important finding.

**Personality inventories** are psychological tests that, unlike the projective techniques, are highly standardized and have considerable empirical validation for what they are designed to assess. As a student, you may have taken one or more of these as part of career guidance, for example. These inventories—for example, the Minnesota Multiphasic Personality Inventory (MMPI/MMPI-2), the California Psychological Inventory (CPI), and the Millon Clinical Multiaxial Inventory (MCMI/MCMI-2)—typically assess personality traits and characteristics and provide a general personality profile of the subject. Other personality instruments are designed to assess specific disorders, such as psychopathy and malingering. Personality inventories or structured interviews can be especially helpful when used in conjunction with clinical findings and projective tests. Perhaps the greatest value of personality inventories is their capacity to spell out, in an objective way, characteristics of the offender that might not otherwise be discerned, or to corroborate a finding that is detected clinically and on projective tests.

Finally, intellectual and cognitive evaluation is essential in any forensic assessment. Conclusions about questions such as an offender's criminal responsibility or competency (discussed shortly) can change dramatically if he or she is found to be intellectually limited or perhaps mentally retarded. Meaningful information often emerges from an offender's response to a test item or group of items. For example, in a 2001 case reported by Schlesinger (see references), a contract murderer who killed more than 100 victims and remained undetected for 30 years had overall intelligence only within the low average range. However, he had superior intellect in areas of social comprehension and practical reasoning, and these strengths helped him elude the authorities for as long as he did.

Because traditional psychological tests were not developed to address specific forensic issues, a number of researchers have developed specialized tests that attempt to focus directly on specific legal questions. These tests are often used in forensic assessments to supplement the clinical interview and traditional psychological testing.

Although these specialized instruments have merit, they often do not add a great deal beyond what can be obtained in a clinical interview that focuses on a specific issue. For example, it is usually not difficult to question an offender about the elements of *Miranda* or the various elements of the competency-to-stand-trial standard. You have undoubtedly seen a television show or movie in which a police officer tells a person who is under arrest that, "You have the right to remain silent …." These are the *Miranda* warnings, and it is clearly important that the suspect understand these. In fact, in some instances, the test may not cover every element listed in a particular state statute; therefore, the psychologist who relies solely on the test may miss some important areas. Moreover, each case rests on its own set of findings, facts, and circumstances. Thus, behavioral scientists rely on a compilation of data, of which testing is just one part.

## 20.3 Forensic Applications of the Behavioral Sciences

### *20.3.1 Uncovering Deceptive Behavior*

In forensic settings, distortion and exaggeration of symptoms commonly occur for a variety of (obvious) reasons. One common type of deception is **malingering** (also referred to as **simulation**), a conscious attempt to feign a (mental) illness; another is **dissimulation,** a conscious and deliberate attempt to minimize or deny symptoms of a mental disorder. Criminal offenders might feign mental illness to avoid criminal responsibility, or they might also deny mental illness to get released from prison or a hospital. Interestingly, offenders who simulate symptoms of an illness often select a currently "trendy" illness, such as multiple personality disorder or posttraumatic stress disorder; moreover, they often greatly exaggerate the clinical picture. Not surprisingly, it is very difficult to maintain consistent malingered psychotic symptoms for extended periods.

Some offenders who commit irrational acts may claim (and actually believe at some level) that there is a rational motive for their conduct. Researchers have found that some sexual burglars steal insignificant objects to convince themselves that they were there not for pathologic reasons (which they do not fully understand) but to commit a robbery. Other offenders try to convince themselves that their offense was unplanned, an accident, or perhaps provoked by the victim. Sometimes an offender's logical and "commonsense" confession of his alleged motive cannot be taken at face value. For example, a man who killed a woman by inflicting 150 stab wounds claimed that he wanted to prevent her from identifying him, and the prosecution accepted his explanation. Here, the authorities tried to make a pathologic act, with complex levels of motivation, seem simple.

### *20.3.2 Competency to Stand Trial*

When considering **competency** of an individual, the question is really, "Competency to do what?" In criminal matters, the primary concern is that of competency to stand trial, but another important competency is that of making a statement to the police or giving a confession. Was the individual competent to make the statement? Did he or she understand his or her *Miranda* warnings, and could he or she voluntarily proceed after having been given the warnings? This is, of course, a retrospective assessment that one has to make, putting together all the data available at the time. Often, the case hinges on whether the confession of the defendant is valid. If the confession is deemed to be invalid, or involuntarily given or coerced by the police, there may be little or no other evidence against the defendant to support the prosecution. There is often great difference in the interpretation by different assessors about the validity of a confession. It is important for the assessing psychiatrist to consider all evidence and all data available. This may include talking with the police officers or detectives who were present at the time the confession was made. Sometimes the defendant will perceive that he or she was coerced by the police officers and made statements that are not corroborated by the evidence of the officers' statements.

The issue of competency to stand trial, however, is perhaps the most important one facing a number of defendants. Most defendants consider themselves competent to stand trial; however, to be found competent, the defendant must be free of mental illness that impacts his or her ability to know what is happening in his or her case. For example, if a defendant does not know what he or she is being charged with or what the consequences of these charges are, he or she may be found incompetent to stand trial. Many states have issued a list of questions that must be asked of the defendant before the assessing psychiatrist can validly give an opinion about competency to stand trial. These factors include the nature of the charges, the consequences of the charges, and the individual's understanding of the courtroom procedure, including the role of the principals in the courtroom. For example, the defendant should know the role of the judge, the prosecutor, his or her own attorney, and the jury. Some defendants may have an intellectual understanding of the nature of the courtroom proceedings but may have delusions about the principals and their roles. For example, one defendant believed the judge and the prosecutor were involved in a conspiracy with each other to find the defendant guilty. That alone may not suffice to vitiate competency, but taken in the context of his total mental illness, which was paranoid schizophrenia and which included delusional beliefs about his own attorney, could be a major factor against his competency to stand trial.

In the pretrial phase, there is also the evaluation of the defendant for competency to plead. Rarely, a defendant may be delusional about a particular case that he or she reads in the newspapers and wishes to confess to the killing and to plead guilty. However, there may be insufficient evidence against him or her and the plea may be invalid because it is based on psychotic delusions. Other forms of competency may arise during the trial phase or post-trial phase. For example, the individual may not be competent to be sentenced to prison because he or she is psychotic and requires mental hospitalization. At a later phase, the individual may not be competent to be executed in the event he or she is given the death sentence (see Sidebar 20.2 and Case Study 20.2.

In the event that a defendant is found incompetent to stand trial, he or she will be hospitalized, usually at a forensic psychiatric hospital where he or she will be treated (or perhaps educated) until he or she is competent. In some rare cases, the defendant, after a period of treatment, will be deemed incompetent to stand trial for the foreseeable future. Under the case of *Jackson v. Indiana* (1972), the defendant will then be committed to a civil hospital after the charges have been suspended, and the case will be treated as a civil case rather than as a criminal case. There is no set time for such assessment, but usually after 1 to 2 years of treatment with no success the psychiatrist may be asked by the court to give an opinion about whether the defendant will become competent in the foreseeable future.

### SIDEBAR 20.2. CURRENT EVENTS: THE TUCSON SHOOTING

On January 8, 2011, Jared Loughner attended an outdoor event in Tucson, Arizona, hosted by Gabrielle Giffords, a member of the U.S. House of Representatives. He opened fire with a handgun and killed six people, including a federal judge and a 9-year-old girl. Thirteen others were wounded. Giffords was shot in the head but survived. Loughner was quickly taken into custody and it was soon evident that his mental state was questionable. He was committed to a prison facility and was evaluated and found to be incompetent to stand trial. A judge ordered that he be given medication, forcefully if needed, to treat his mental illness. After about a year, he was deemed competent to stand trial by a group of experts. An agreement was reached with prosecutors and he pled guilty to the 49 counts against him. This allowed him to avoid the death penalty.

**CASE STUDY 20.2: COMPETENCY**

The competency to confess has been an issue in a number of cases. The one we will now describe concerns a young man who claimed that the police did not read him his *Miranda* rights and did not deal with him fairly. He said they threatened him and beat him, although there were no physical marks of beating. The problem was the police did not audiotape or videotape the confession and the statement that he made, nor the proceedings by which the confession was obtained. Many jurisdictions mandate videotaping all statements and confessions, but others do not. From a forensic psychiatric standpoint, it appears to be a good idea for police departments to videotape, or at least audiotape, the statements made by suspects so that when evaluation or assessment is conducted later there is a record that will support their contention.

In this particular case, the individual was articulate and hired several individuals who substantiated his claim that his will was overridden and that he did not give a truly voluntary statement. This is a man who had a longstanding antisocial personality disorder and who had been involved in a number of different kinds of crimes and had escalated his criminal behavior from fraud to burglary to robbery to homicide. It was clear, from a total assessment of the individual, that he was attempting to have the case thrown out by claiming that his statement was not voluntary and there was very little objective evidence beyond his statement for the prosecution to use in sustaining a conviction. After heated testimony on both sides, the judge determined the statement was competently given and could be admitted into evidence. The defendant then had no choice but to plead guilty and accept a negotiated plea for life imprisonment rather than the death sentence.

### *20.3.3 Legal Insanity*

The definition of **insanity** varies in different jurisdictions. Most states follow the **McNaughten rules**, which were promulgated in England in 1843. McNaughten rules are primarily a cognitive test of insanity. Most jurisdictions indicate that a person would be found not guilty by reason of insanity if, at the time of the commission of the crime, the person was suffering from such mental infirmity or disease that he or she did not know the nature and quality of his or her action. This is purely cognitive in that the individual could not or did not know what he or she was doing or that what he or she was doing was wrong.

Modifications to the McNaughten rules have been attempted in various jurisdictions over the past several years. Adding a volitional arm to the test has been attempted in that if a person did know what he or she was doing and did know that it was wrong and yet could not control his or her behavior, then the individual would be found legally insane. Perhaps the most ambitious attempt was made by the American Law Institute Model Penal Code, which was introduced by Judge Bazelon in the *Brawner* case in 1972, replacing the *Durham* decision of 1954 that Judge Bazelon had promulgated in the District of Columbia Court. *Durham* stated that a person would be found not guilty by reason of insanity if the person's behavior was a product of mental illness. That test proved to be too broad and too inclusive and was not helpful in discriminating the insane from the sane. Judge Bazelon, in the *Brawner* case, then adopted the Model Penal Code of the American Law Institute, which stated, "A person would be found not guilty by reason of insanity if at the time of the commission of the crime the person lacked substantial capacity either to appreciate the criminality of the behavior or to conform his conduct to the requirements of the law." In that test, there are three elements of the mental state: cognitive, conative (emotional), and volitional. It was the test used in the *Hinckley* case in 1982 that led to the finding of not guilty by reason of insanity for John W. Hinckley, Jr.

It was also following that finding of not guilty by reason of insanity that Congress changed the law for the federal jurisdiction in 1984, adopting the Omnibus Crime Code for Insanity, which stated that a person would be found not guilty by reason of insanity if at the time of the commission of the crime the defendant could not appreciate the criminality of his behavior. The use of the word "appreciate" broadens the scope that limits McNaughten to "knowledge." The law also prohibited the psychiatrist from addressing the ultimate question of insanity. He or she could give an opinion about mental illness and its effect on the defendant, but could not give an opinion about insanity, which was the domain of the jury or the trier of fact. The burden of proof also switched from the prosecution proving sanity beyond a reasonable doubt to the defense proving insanity to a clear and convincing degree.

Also following the *Hinckley* decision was the concept of "guilty but mentally ill." It is improper to state "guilty but insane" because insanity indicates a lack of ***mens rea***. A crime consists of two parts: the guilty act (***actus reus***) and the guilty intent (*mens rea*). To vitiate one of those (that is, the *mens rea* by insanity) could not then lead to a guilty finding. The concept of "guilty but mentally ill" was adopted in 13 states, and in Pennsylvania the definition of mental illness is that of the American Law Institute Model Penal Code, which is that the person lacked substantial capacity because of mental illness either to appreciate the criminality of his or her behavior or to conform his or her conduct to the requirements of the law. In Pennsylvania, if a defendant pleads "not guilty by reason of insanity," the judge must also read the charge for "guilty but mentally ill."

### *20.3.4 Diminished Capacity*

Another concept involving the state of mind of the defendant at the time of the commission of the act is that of **diminished capacity**. Diminished capacity has different meanings in different jurisdictions. For example, in Pennsylvania, the concept of diminished capacity reduces the degree of homicide from first degree to third degree only. The concept is that a person could not form the specific intent to kill and, therefore, the degree of the homicide is reduced from first to third degree. In New Jersey, however, the concept has a much more profound meaning in that it is a total defense and that if a person is found to have a diminished capacity—that is, the individual could not act purposefully or knowingly—then he may be acquitted of the charges against him. Generally speaking, diminished capacity means that the individual at the time of the commission of the alleged offense had a diminished ability to meet all of the criteria for the charges against him; that is, the individual could not or did not form the specific intent or could not act in a knowing and purposeful manner.

### *20.3.5 Dealing with Sex Offenders*

Society has always been in a quandary about how to handle the repeat sex offender, whose conduct obviously stems from psychological sources. The serial rapist, child molester, exhibitionist, voyeur, and sex murderer have been present since pre-modern times, and the serial nature of such offenses, as well as their general repulsiveness, made resolution of these problems foremost in the minds of legislators. Accordingly, mental health professionals offered their expertise in both diagnosis and treatment of such offenders. Beginning in the mid-1930s, many states took psychologists and psychiatrists up on their offer and enacted various **sexual psychopath laws**, which mandated the evaluation and treatment of sex offenders. The expertise of psychiatrists and psychologists was readily accepted, in part, as a way to allay public hysteria resulting from some brutal sex crimes. By the end of the 1960s, almost every state had developed specialized diagnostic and treatment programs dealing with sex offenders.

By working in sex offender programs, psychologists developed considerable expertise with this population of offenders, whose psychopathology was very different from the type usually encountered in general clinical practice. However, by the early 1980s, initial optimism faded into embarrassment as many offenders—deemed suitable for release—continued to commit offenses. Despite the noble intentions of both the law and mental health practitioners, many states concluded that sex offenders simply could not be successfully treated. By the late 1980s, therefore, many states closed their programs (in part or whole) and mandated longer periods of incarceration; treatment now played a secondary role, if any role at all.

### *20.3.6 Post-Trial Sentencing*

Behavioral scientists may be called by the court to give opinions about the sentencing of a particular individual who may require treatment in a psychiatric hospital or may require medication. The psychiatrist will give testimony at the request of the court in such cases. There may be specific needs the defendant would have in a particular institution. The psychiatrist is presumed to be well versed on the treatment facilities in the community and give such testimony for the court's assessment regarding sentencing. In a specific case of death penalty issues, the psychiatrist may be called to testify whether the defendant is competent to be sentenced to death. He or she may also be called to testify whether the defendant is competent to be executed at a later date. There are also issues where the defendant has asked for all of his or her appeals in the death penalty case to stop and asks that he or she be executed summarily. The forensic psychiatrist may be called to evaluate the competency of the individual at that time to determine whether he or she is competent to waive his or her rights under the Constitution.

## 20.4 Behavioral Science at the Crime Scene

Understanding the motivation, thoughts, and forces that drive violent criminal behavior is clearly challenging for those who do not share those predilections. Offenders often leave trace evidence consisting of fingerprints, footprints, tire tracks, DNA materials, hair, threads from clothing, etc. Likewise, an offender leaves behind traces of behavior at the crime scene. This behavior can be inferred logically by an experienced investigator and this is the basis of what is called generically "profiling." **Profiling** has been given many definitions. One helpful view is to define profiling as the identification of certain characteristics of an unknown, unidentified offender based on the way he committed a violent act and his interactions with the victims. By reading the offender's behavior at the crime scene, certain descriptive traits and characteristics can be attributed to the unknown offender. Some traits are learned from witness descriptions, but the most valuable clues are based on a combination of crime scene examination, investigative experience, an understanding of offender and victim behaviors, knowledge of wound patterns, forensic evidence, and the existing research in the field.

As an example, interviews with experienced criminals and a review of their criminal acts revealed two distinct patterns in homicidal offenders, with some actors falling in the middle ground. **Organized offenders** exhibit clear evidence of forethought regarding their approach to and subsequent dealing with a victim. They plan and rehearse the crime in detail, allowing for variances in victims and locations. They conceive, before the crime, what will be necessary to prevent identification and apprehension and what tools or implements will be needed to efficiently deal with the victims in the manner they desire. Within the constraints of their ability to fantasize and imagine, they leave little to chance. They leave few clues as to identity and select victims who cannot be linked to them; however, by doing so, it can be inferred that they were organized in their thoughts and actions. **Disorganized offenders** are well defined by their impulsiveness and generally thoughtless approach to crime. Their crimes will typically be messy and chaotic, with reliance on using criminal tools readily available at the crime scene. Their lack of planning often results in abundant clues to their identity and a plethora of identity-linking evidence at the crime scene. Cardinal indicators of disorganization are usually found in the evidence surrounding their ability to approach, obtain, and maintain control of the victim throughout the crime.

As noted above, fantasies are powerful forces in shaping violent criminal acts. Fantasies play a critical role in many crimes but have their greatest impact in sexually violent crimes. Fantasies do not create criminality, but they do reinforce and deepen criminal thought. Fantasies are daydreams. They may be positive and enriching, or they may be negatively focused on power, control, and domination. Fantasies may be visualized on a continuum, ranging from the low point of repetitive, underdeveloped thoughts through repetitive, detailed, well-developed, elaborate, and coherent thoughts. Offenders using the latter type of fantasy are noted for having more “evidence-free” crimes due to the repetitive nature of the thinking pattern wherein the criminal planning is more extensive, more well-rehearsed mentally, and subsequently more effective. Criminal sophistication can often be seen in this type of criminal fantasy. A prime reason for the difference in fantasies and, hence, a difference in offenders is the ability to use imagination. Imagination is a forerunner and indicator of intelligence. Intelligence in fantasy generally leads to more effective planning and corrective thinking that is often seen as criminal sophistication. Hence, the more elaborate the fantasy, the more evident the sophistication and the more difficult the task of the investigator.

Fantasies may be used to organize a collection of deviant thinking into a criminal thought pattern. This is commonly referred to as **premeditation**, which is related to organization. Fantasies may become evident in sexualized violence as those crimes often feature behaviors that go well beyond acts that are strictly necessary to accomplish or complete the intended criminal act. As a person fantasizes over time, he develops a need to express those violent fantasies. Most serial killers have been living with their fantasies for years before they finally bubble to the surface and are translated into behavior. When the killer finally acts out, some characteristic of the murder will reflect a unique aspect played over and over in his fantasies. Likewise, retired New York Police Department homicide detective Vernon Geberth (see references) wrote that it is not enough simply to consummate the murder; the killer must act out his fantasies in some manner over and beyond inflicting death-producing injuries. This "acting out" is the **signature** of the killer. All of these factors and characteristics play into how a perpetrator behaves at a crime scene and what kind of behavior evidence is left behind.

### *20.4.1 Modus Operandi and Signature Analysis*

The concept of **modus operandi (MO)** has been subjected to extensive analysis through the criminal appeals of serial offenders, and its definition has remained stable. It becomes relevant when a perpetrator commits more than one crime and a series of linked crimes is suspected. The phrase *modus operandi* first appeared in literature in 1654 in a piece called *Zootomia*: "Because their causes, or their modus operandi (which is but the Application of Cause and Effect) doth not fall under Demonstration." By the middle of the 20th century, modus operandi identification techniques and procedures became a standard part of criminal investigation literature. The investigative use of modus operandi began to change in the late 1980s. It became apparent that the MO of an offender would change slightly from crime to crime. For example, a burglar who normally used a pipe wrench on the front doorknob to gain entry might change his MO after discovering that the front door was unlocked. Thus, the burglar would enter through an unlocked front door without using the pipe wrench and his MO changed to fit the circumstances. Also, it became apparent that a murderer or rapist would have to do the same thing from crime to crime.

A criminal's MO is not the only behavioral characteristic than can assist investigators in linking crimes. A killer's signature is left at each crime scene across a spectrum of several murders. For example, when the killer in one murder intentionally leaves the victim in an open and displayed position, posed physically in a spread-eagle position as if for a bizarre photographic portrait, and when he savagely beats the victim to a point of overkill and violently rapes her with an iron rod, you have to consider such behavior as fundamentally unusual. When a second murder is committed in which the killer has done the same things as in the first, even though he may slightly modify one or two of the features, there is little doubt the two murders are related.

It is important to note that an MO and a signature are not the same thing. An MO is simply the way a particular criminal operates (see Case Study 20.3). If a criminal commits breaking-and-entry burglaries by using a glass cutter to get through a door and suctions the glass away so it does not fall to the ground and make noise, that's his MO. If the criminal uses flypaper instead of a suction cup to hold the glass fragments together so they do not make noise, that is a different MO. When police find flypaper traces at a crime scene, they go back to their files and look for breaking-and-entry burglars who have used flypaper and use this knowledge to form a list of suspects. For the crime of murder, MO includes only those factors necessary to commit the murder and can change over time. Basically, an MO accounts for the type of crime and property attacked, including the person, the time and place the crime was committed, the tools or implements used, and the way the criminal gained entry or how he or she got his victim, including disguises or uniforms, ways he represented himself to a victim, or props such as a bike or crutches.

Beyond the MO, many killers are not satisfied with just committing the murder; they have a compulsion to express themselves or do something that reflects their unique personality. The killer's personal expression is his signature, an imprint he leaves at the scene, an imprint he feels psychologically compelled to leave to satisfy himself sexually. Unlike the characteristics of an offender's MO, the core signature remains constant. However, a signature may evolve over time, as in some cases

## CASE STUDY 20.3: THE SHORELINE MURDERS (MO AND SIGNATURE)

The Shoreline district lies north of the city limits of Seattle, Washington, and was the site of two murders in 1995. Not many murders occur in the area over a year; in the previous year, the neighborhood experienced the average variety of crimes and one murder of a male victim. However, within 30 days, the locale experienced two separate, atypical murders within the same apartment complex (Figure CS20.3.1). Eventually, Robert Lee Parker, a resident of that apartment complex, was arrested, charged, and convicted of the killings. Both physical and behavior evidence was crucial in linking the crimes.

The first victim, Renee Powell, was a registered nurse who worked in several hospital facilities in the area. Powell was described as a 43-year-old white female, 5 feet 4 inches tall, small build, and weighing 100 pounds. She had no criminal record and had not been a crime victim. Powell was last seen alive at approximately 7:30 p.m. on February 24, 1995. Previously, she had driven to a nearby Albertson's Supermarket to purchase cigarettes, a newspaper, and some ice. Police investigation revealed that upon returning to her apartment on 197th Place she had sufficient time to make a jar of iced tea. Also, it was discovered that Renee was doing laundry in the building's laundry room, which was adjacent to her lower apartment unit. The apartment structure was a two-story residence containing four units. No one would see Powell again until firemen discovered her charred remains inside her apartment shortly after midnight on February 25.

Firemen responding to the scene extinguished the blaze and discovered Powell's body. She had been bound, gagged, and constrained by a ligature. Investigation revealed that Powell probably heard a noise at the front door of her apartment because the killer had broken her door open. She probably had no time to respond. Powell was discovered face down on the floor of her bedroom with a bookshelf pulled down and lying on top of her body. The killer appeared to have stripped her naked from the waist down and then tore her shirt from her body. Her bra remained fairly intact, pushed up, exposing her breasts. Her

***Figure CS20.3.1*** Aerial view of Powell and Walsh's apartments in proximity to Parker's residence.

left arm was bound with an electrical cord cut from a study lamp later found in her bedroom. Eventually, arson investigators determined that separate and distinct fires had been started around the residence.

The autopsy examination discovered that Powell suffered two stab wounds. One was in the right abdomen and stomach; the other, in her left back. The gag was an elastic bra, tied tightly and fastened in the back with a double overhand knot. The medical examiner removed a segment of electrical cord from around the victim's left forearm and outside of the shirt. The loops were tied with a complicated set of overhand knots. The plug end of the cord was present and the other end appeared cut. The presence of conjunctival petechiae indicated that there was probable asphyxia. The victim's body was more badly burned in the front than in the back. There was no soot found in the throat; therefore, death occurred before the fires. Powell had been vaginally raped, and semen was preserved as evidence. Further investigation revealed that the killer had stolen items from the apartment, including an overcoat, a dress, a videocassette recorder, several bottles of wine, a duffel bag, and some frozen meat.

The second victim was Barbara Walsh, a 54-year-old white woman who lived alone in the same apartment complex as Renee Powell. Walsh worked as a receptionist at Group Health Hospital. Thirty days after the murder of Renee Powell, at about 10:30 p.m., a neighbor saw Barbara Walsh returning from the laundry room of their fourplex, located about 100 yards northwest of Powell's apartment. Unlike Powell's one-door apartment, Walsh's had a front door and a back sliding door that opened to a common patio and a wooded area. Her sliding door could not be unlocked from the outside, so police investigators surmised that during one of Barbara's trips down to the laundry room the killer slipped inside.

At about 1:06 a.m. the following morning, neighbors reported smelling smoke and discovered a fire in progress in Walsh's apartment unit. Fire personnel extinguished the fire and discovered the body. They could see that she was face down, bound, and gagged with a ligature. She was found on the floor of her bedroom with her head next to the foot of her bed. She was nude except for her shirt, which was shoved up nearly to her neck. Multiple fires had been set within the apartment.

The autopsy report stated that Walsh was gagged with three pairs of tights and she died as a result of ligature strangulation. On her left wrist was a ligature that was extensively burned and consisted of multiple types of wires. There was a 9-1/2-inch length of black insulated wire, incompletely burned through and attached by a few strands to a portion of yellow-tan insulated wire. The yellow-tan wire, from a lamp in the residence, was wrapped and knotted circumferentially around her wrist. One portion of the wire completely encircled the thumb. She suffered three stab wounds clustered on the right side of her abdomen. The stab wounds were gaping and extensively charred around the edges. Near this cluster of wounds was a solitary stab wound. A ligature was present on her left wrist and multiple abdominal stab wounds were identified that produced injuries insufficient to account for her death. The thermal injuries were incurred after death, and no soot was present in her throat. The knife used had a 7-inch blade attached to a 4-inch handle and was found on the couch where one of the fires was started. (Figure CS20.3.2). All of the materials used by the killer belonged to the victim and several items were taken from the victim's residence.

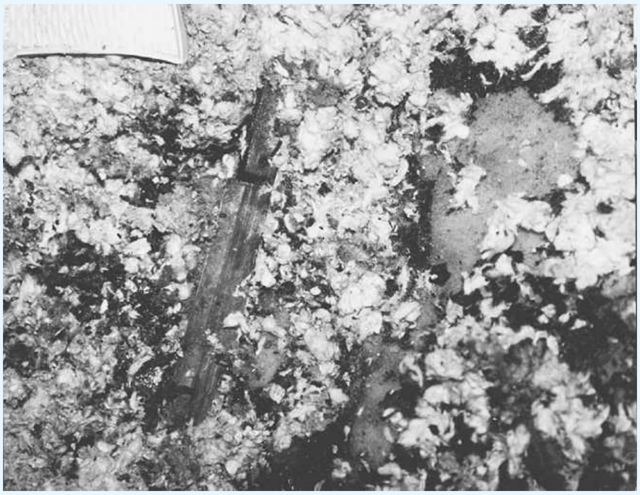


***Figure CS20.3.2*** Knife used in the Walsh murder, found on the couch where one of the fires was started.

Investigators were able to piece together the elements of the killer's signature based on evidence from the scenes, autopsy reports, and other findings. First, the act of binding was present in both murders. The killer used binding materials found at the scenes rather than bringing his or her own materials. The use of electrical cord and the ligatures exceeded the necessary violence to control the victims for rape–murder. The electrical cord binding and loops around both victims were the specific and necessary control devices that the killer had to use at each crime scene.

The number of stabbing strokes was important for this killer, and they increased from the first murder to the second murder. The killer stabbed Powell, the first victim, twice and inflicted four stab wounds on Walsh, the second victim. Third, the disposition of both victims' bodies reflected this killer's

where a necrophilic killer performs more and more postmortem mutilation from one murder to the next. Other examples of signatures are mutilation, **overkill**, carving on the body, leaving messages, rearranging or positioning the body, engaging in postmortem activity, or making the victim respond verbally in a specified manner. What is important about a killer's signature, then, is that killers learn to treat victims the way they do in their fantasies, always attempting to satisfy their fantasies as they move from one victim to the next.

### *20.4.2 Profiling*

Profiling evolved from work initiated by the FBI's Behavior Science Unit, now called the National Center for the Analysis of Violent Crime (NCAVC), and has its origins in the 1970s. Not surprisingly, profiling was viewed as a major breakthrough by some and skeptically by others. The term, still widely used today in law enforcement and the behavioral sciences, saw some success, and as it evolved several other processes were lumped together under the general definition of profiling. We will talk about some of these aspects shortly. The purpose of offender profiling is to supply offender characteristics to help investigators narrow the field of suspects

***Figure CS20.3.3*** Location of the towel in Walsh's bathroom. Hair, linked by DNA profiling to Parker, was found under the towel.

personal feelings. The killer had to leave the victims in a sexually degrading and submissive position. Both were essentially nude from the neck down and intentionally placed face down. The killer purposefully left the victims so they would be found. Finally, the taking of souvenirs enabled this killer to relive the event at some future time. Thus, as the killer proceeded from one victim to the next, his true signature evolved. More stab wounds, more percussive activity with the body, and additional fires allowed this killer to feel more attached to his victims and vent his anger. These factors led to the conclusion that the two victims were killed by the same person. Physical evidence was also crucial in the case and linked Parker to both murders. Semen found on Powell's vaginal swabs was found to match Parker's. In addition, hair was found on Walsh's bathroom counter. The hair was protected from the fire by a towel that lay on top of it (Figure CS20.3.3). DNA analysis was performed on the hair and compared to Parker's DNA, and another match was discovered.

based on the characteristics of the crime scene and initial investigative information. Categories of descriptors include the following: sex, race, age (approximate), criminal history, residency in relation to the crime scenes, employment history, social adjustment, sexual adjustment or abnormalities, alcohol or drug usage, educational level, and interpersonal skills. Profiling is used principally as an aide to investigators rather than as evidence in court.

### *20.4.3 Victim Selection*

The psychological processes involved in the selection of victims range from simplistic to complex, depending on the offender's motivation. The complexity is somewhat commensurate with the richness of the offender's fantasy, criminal sophistication, and constraints of the moment. When a victim is targeted, it is an indication of some level of association between the victim and the offender. Other victims may have merely had the misfortune of being "at the wrong place at the wrong time." Some offenders have idealized their victim type and involved them in their mental play acting; conversely, offenders may act with impulsivity and choose a victim simply based on her availability.

Some of the more elusive serial killers have established selection rules for their victims. Such rules are unknown to the victims, and how they respond to gambits thrown their way by the offender often determines their fate. In these situations, the offender creates scenarios and measures the victims' attitudes and responses to determine if they measure up to the standards he has established. The infamous Ted Bundy created an idealized standard for his victims wherein they had to be "worthy" of his selection.

One common finding within the victim selection process involves a conscious evaluation of the victim as to whether the offender can control her or if she will present a special challenge to his criminal planning abilities. As one serial rapist explained to one of the authors, he graded the victim's evident level of confidence and assertiveness before approaching her. If the potential victim was wary, he avoided her. If the potential victim were confused by her surroundings or oblivious to events surrounding her, he would assess these signs of weakness to determine his chances of success with that particular woman.

### *20.4.4 Victimology*

One good source of information for investigators trying to understand the crime scene involves detailed knowledge of the crime victim's life and lifestyle. The history of a victim in some ways defines the analysis of the crime. From one perspective, unsolved violent crime frequently results from an incomplete or faulty understanding of the victim. So important is this phase of investigation that the study of the victim must be thorough and undertaken immediately. People have a variety of personality factors, even quirks, which help define them and can contribute to their being targeted. The victim's characteristics may also offer insight regarding the personality of the attacker. Why was that person attacked instead of some other person? The goal is to develop sufficient **victimology** to be able to answer the question: "Was the victim's lifestyle a contributing factor toward victimization?" As the investigator initiates the search for the perpetrator, a full understanding of the crime scene and interactions between the victim and the offender may be elusive. Unfortunately, cases have remained unsolved because key information about the victim and his or her lifestyle has not been uncovered. These intimate details usually explain or clarify why victimization occurred with this victim, at this particular location, at this time, in this particular manner, and by this particular offender.

### *20.4.5 Trophy or Souvenir: What Is Taken from the Victim?*

The psychological processes of offenders are varied and personalized. Different offenders may commit the same or similar acts, but their psychological frames of reference may be dichotomous. An excellent example of individual differences in offenders is demonstrated by the significance attached by the offender to the items taken from the victims. These items fall into three general categories: evidentiary, valuables, and psychological. As part of the offender's MO, he may take evidentiary items that tend to identify him, leading to his arrest. The offender may take valuables to fulfill his or her motivation for financial gain, or the offender may take items of minimal value; often, items of little monetary value are not missed. This category of (non-valuable) items falls into the realm of the offender's psychosexual motivation, drive, and thinking. These thefts have nothing to do with protecting the identity of the offender or fulfilling the purpose of financial gain; rather, they are driven by an inner need of the offender, a drive that takes behavior beyond what is required for the offender to be successful in his criminal endeavor.

These same items may be taken by different offenders in different crimes while working with similar MOs, and with similar type victims. However, the reasons for the behavior may be very dissimilar in that the stolen items are closely identified with the victim or the commission of the crime. They are called either a **trophy** or a **souvenir**, depending on the meaning placed on them by the offender's mental process. In the mind of the offender, the item retained may represent an accomplishment, a victory within the context of his criminality, so it is retained as a trophy. For other offenders, the same item would represent, to him, a fondly remembered occurrence and is retained as a souvenir for inclusion in his masturbatory fantasies.

### *20.4.6 Crime Scene Staging*

On occasion, investigators will find a crime scene that has been tampered with before the arrival of authorities. This is referred to as **crime scene staging**, which involves acts that are committed to send the investigation off course and away from the offender. A crime scene may be staged to mislead the investigator from considering a particular person a logical suspect. An example of this type of staging might involve a man who kills his wife and wants the police to believe the homicide was committed by a burglar. His efforts would be directed toward causing the scene of death to include aspects that suggest the offender came to steal or rob. Staging may be attempted by ransacking a bedroom, a jewelry case, or by removing valuables from the premises.

Innocent family members who discover a body in a position that is personally disturbing to them may also stage a scene. The body may be nude or the manner of death may be unacceptable to the family as it offends their values. A good example of this would be the discovery by the wife of a husband found hanging in the basement, partially clothed. The wife may assume her husband committed suicide. If suicide violates strict religious beliefs or causes concern regarding specific clauses in an insurance policy, the wife may alter the scene. To overcome objectionable aspects, she may rearrange the body, to include redressing the victim. These acts, while possibly criminal, are usually motivated to achieve protective goals and may mislead the investigator.

In both scenarios, the investigator will likely find multiple aspects of the crime scene that are inconsistent. The various details of the crime scene will be **internally inconsistent**, which means they will not fit together logically, nor will they be properly supported by forensic evidence. As an example, the husband who killed his wife may have committed the crime out of uncontrolled anger. If so, the crime scene will usually display facets of that anger within the evidence present. The injuries inflicted on the wife's body may reflect overkill. The forensic and behavioral aspects of her death will reflect anger; however, the staged portions will reflect elements of burglary. These inconsistencies will alert the investigator to look for other incongruent clues. If the crime scene has been staged, a pattern of incompatible features will likely be discovered. The discovery of inconsistent details may include staging of the point of entry, the items that are missing from the crime scene, or the nature of the assault on the victim. The most likely tip-off that the scene has been staged may be the husband's display of emotion or his story about the crime. They generally do not correctly approximate the details reflected by an analysis of the crime scene.

### *20.4.7 Body Disposal*

Offenders have choices to make when confronted with the reality that they have murdered another person and now have a body to dispose of. The body disposal location and methodology are often revealing as to a prior victim and offender relationship, the offender's criminal sophistication level, the degree of planning by the offender in committing the crime, the attitude of the offender toward the victim as an individual, whether the victim represented a class of people, and the offender's knowledge of the body disposal site. The location may indicate whether or not the offender resides close to the crime scene and body disposal site. The choices facing the offender are limited. He may simply walk away from the body, abandoning it where it fell, or he may choose to spend a brief or a considerable time concealing the body. The offender may arrange the body in a manner that, in his thinking, makes a statement about the victim. Furthermore, he may also move the body to another location and dump the remains at the second location.

To walk away from the body, abandoning it where it fell, may signal a lack of planning or forethought. It may also suggest a certain pattern of "disorder" that might lead to the conclusion that the crime was more spontaneous and impulsive, rather than controlled and thought out. The offender who invests time and effort in concealment of the body suggests that he has thought about the crime and is aware of the need to delay discovery of the body; the offender may need time to establish an alibi because his name will likely surface in the investigation. The concealment of the body also serves the purpose of concealing any linking evidence, thereby denying the investigator vital information on which to establish an investigation based on linkages to known associates or activities. A highly organized offender may choose the disposal site prior to selecting the victim.

The murderer who chooses to pose the body is likely attempting to achieve one of two goals. He may be trying to leave the body in a way that offends the discovering party, or society in general. The alternative is that the offender may be expressing his inner thoughts or anger and hatred toward this victim in particular or others represented by this victim (possibly prostitutes, drug dealers, etc.).

By moving the body to another site, the offender creates multiple crime scenes (primary, secondary, etc., as we discussed in Section 2). The vehicle used for transportation becomes a crime scene, as does the new location. The significance of the acts is related directly to the thought process of the offender. If the movement is part of the process of concealing the body, those acts are likely from an organized offender, who has specific goals in mind to protect his identity or delay the discovery of the crime. The movement of the body may be to place it in an area where it will not be found or, if found, the area itself would be noted for specific activity, such as a lovers' lane or a trash dump site. The movement of the body may also accomplish the purpose of allowing the offender to simply dump the body in a more remote area. Such actions often provide critical hair, fiber, and DNA forensic evidence that can be found in vehicles; such evidence often links the victim to the specific offender.

## Chapter Summary

The behavior sciences have made a significant contribution to forensic sciences, particularly in the last few decades. Behavioral scientists such as forensic psychologists and psychiatrists are now involved in nearly every phase of legal proceedings and criminal investigations. The most famous application, profiling, is built upon the tenet that physical evidence, such as that left at a crime scene, reflects the behavior of a perpetrator, and that behavior reflects personality. Psychologists have developed a number of tests to quantify some aspects of personality, but many other factors such as interviews and research form the basis of interpreting behavior. One of the most important contributions of the behavior sciences to criminal investigation is the ability to link multiple offenses to a single offender by studying such things as their MO and signature. While not often used in courts, this information can prove vital in the investigative phase of an investigation.

## 20.5 Review Material

### 20.5.1 Key Terms and Concepts

*Actus reus*
Competency
Crime scene staging
Diminished capacity
Disorganized offenders
Dissimulation
Insanity
Internally inconsistent
Malingering
McNaughten rules
*Mens rea*
Modus operandi (MO)
Organized offenders
Overkill
Personality inventories
Premeditation
Profiling
Projective tests
Psycholegal
Psychological autopsies
Psychological testing
Sexual psychopath laws
Signature
Simulation
Souvenir
Thematic Apperception Test (TAT)
Trophy
Victimology

### 20.5.2 Review Questions

1. What is the difference between MO and signature?
2. What are the similarities and the differences between forensic psychology and forensic psychiatry?
3. What does it mean when we say the findings at a crime scene were "internally consistent"? Give an example of what would constitute inconsistent findings.
4. What is meant by a "projective test"?
5. What is the distinction between a clinical and a forensic assessment?
6. Discuss complicating factors in forensic assessment, specifically with regard to deception.
7. Feigning an illness is called __________.
8. To be found competent to stand trial, what does a person need to be able to do?
9. For a person to be found legally insane, it must be shown that the person had a mental illness that prevented the defendant from doing what?
10. For a defendant's statement to the police to be valid, the statement must be __________ and __________.
11. How frequently is the insanity defense raised in criminal cases?
12. For what purpose may a forensic psychologist or forensic psychiatrist be called by the court after a verdict has been given?

13. For what purpose, following a death penalty sentence, may a forensic psychologist or forensic psychiatrist become involved?
14. What are the McNaughten rules?
15. Discuss the concept of case linkage analysis and the roles played by MO, signature analysis, and profiling in linking cases.
16. What is victimology? How is it used?
17. What is a "profile"? What are its limitations and uses?
18. What are trophies and souvenirs? How are they similar and how are they different?
19. Discuss the role of fantasy in criminal conduct. How can fantasies be revealed at the crime scene?
20. What is the meaning of the terms *actus reus* and *mens rea*? How do these concepts relate to behavior forensic science?
21. How could an organized offender be differentiated from a disorganized offender based on physical evidence at the crime scene?

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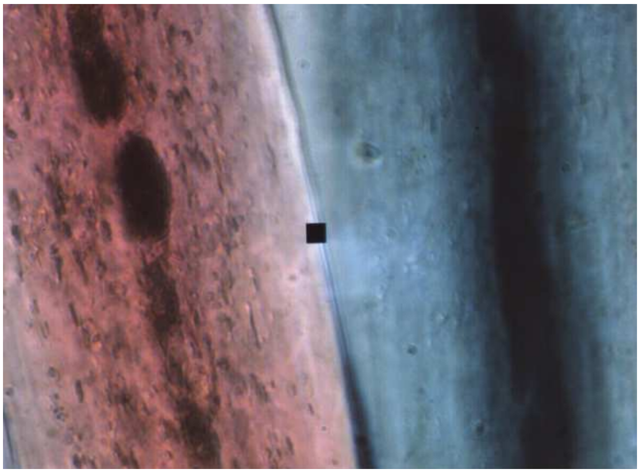
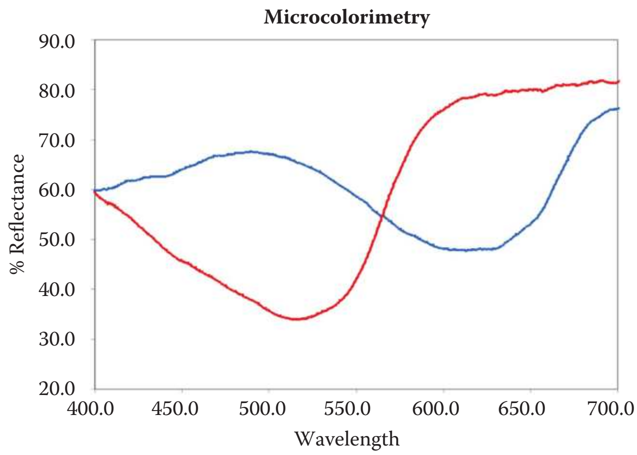
# 21

# The Future of Forensic Science






## Chapter Overview

This purpose of this chapter is to bring the book to a close by examining where forensic science appears to be heading. Because of the unique role of forensic science, serving the justice system as well as the scientific community, predictions are always difficult. For example, we can't say that wherever the cutting edge of science is, that is where forensic science will be. Why? Because as we have seen, forensic applications of science and technology have to be vetted by two communities that use two different systems: science (scientific method) and the law (adversarial system). As we discussed in the early chapters of the book, that is not always an easy task. What we can be sure of is that forensic science will change; it must, based on the National Academy of Sciences 2009 report entitled *Strengthening Forensic Science in the United States: A Path Forward*. As this edition went to press, two pieces of legislation had been introduced into the U.S. Congress to implement recommendations found in the report.

# Chapter 21
# The Future of Forensic Science

*Suzanne Bell*

## Chapter Outline



## 21.1 Overview

One of the most interesting and far-reaching developments in forensic science that has occurred over the past quarter century or so has been the development, acceptance, and use of DNA typing technologies in forensic science. This coincided roughly with legal decisions that have become central in forensic science such as *Daubert*, *Joiner*, and *Kumho* (all discussed in Chapter 2). As courts became accustomed to evidence presented with a probability (the odds of a DNA match) and to increasing stringency in admission proceedings, the pressure increased on many forensic disciplines that do (or did) not routinely use statistics and probability. These disciplines were primarily those associated with pattern evidence such as fingerprints, firearms and tool marks, and tread wear impressions. Thus, the use of statistics and probability in forensics will inevitably become more commonplace in the years ahead.

The legal decisions handed down during this same period are also driving change in forensic science, particularly the *Daubert* trilogy. Although not all jurisdictions use *Daubert* criteria for determining admissibility, what these decisions do provide is a guideline by which the trier-of-fact can determine admissibility. These criteria include asking such questions as

- What standards are available for this methodology?
- What is the known (or potential) error rate of this methodology?
- Can this method be tested and falsified?
- Has this methodology been accepted by the scientific community?

We can expect forensic science and the legal community to continue to adapt to these types of questions even if the *Daubert* standards are not used. One clear implementation is the scientific and technical working groups that have been formed to address individual forensic science disciplines.

## 21.2 TWGs and SWGs

About 20 years ago, the National Institute of Justice (NIJ) and other agencies began forming technical working groups (TWGs) specific to different forensic disciplines. TWGED, the technical working group for forensic science education, was formed as a resource for developing forensic science education programs. This group eventually became FEPAC, the Forensic Education Programs Accreditation Commission, which now oversees accreditation of bachelor's and master's forensic science degree programs. Similarly, other TWGs have become scientific working groups (SWGs), several of which have been mentioned in this book. Many, but not all, are funded by the NIJ. The Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG; http://www.swgdrug.org/), for example, is funded by the Drug Enforcement Administration, while the Scientific Working Group on Dog and Orthogonal Detector Guidelines (SWDOG; http://www.swgdog.org/) is funded by several agencies. The role of SWGs has slowly expanded, and now many groups offer recommendations for what could be called "best practices" for a given type of analysis or evidence. For example, the Scientific Working Group for Gunshot Residue (SWGGSR; www.swggsr.org) has published a guide for the analysis of primer residue using scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDX) methods (as discussed in Chapter 15). Although none of these recommendations is mandatory, they do provide a baseline for laboratories and their methods. It is likely that SWGs will play an increasingly important role in improving forensic science practice.

## 21.3 Crime Scene Investigation

Crime scenes are where forensic science often begins so it is no surprise that there is strong interest in improving crime scene processing techniques. The ideas being explored currently include the expanded use of instrumentation at crime scenes and improved methods of documentation including three-dimensional (3D) imaging and recording. The latter is of particular interest given that a crime scene begins to change and decay the instant that it is created; the more thorough the documentation, the more likely it is that important information can be recovered from that scene later. Some institutions are working to develop 3D crime scene training facilities, as well, which could enhance the training currently available to crime scene responders.

The interest in new instrumentation to be used at crime scenes is not new, and often the use of instruments at scenes has to be carefully considered in the light of many different considerations. For example, advanced mass spectrometers might be useful at a crime scene, but often these instruments are complex and require significant training and experience to operate in a reliable way. Simply miniaturizing instruments and sending them into the field is thus not as simple or as valuable as you might expect (at least not yet). Another example is the interest in developing miniature and rapid DNA analysis methods that can be used at crime scenes and military checkpoints and for intelligence gathering and rapid identification. Commercial instruments developed for these applications are currently being tested; however, in the short term there will be limitations to their usefulness. For example, a DNA profile is just that; to link that profile to a person, some type of previous data or database is needed. Integrating a DNA analysis method into CODIS is neither quick nor easy. This does not mean that the ability to rapidly type DNA is not useful; rather, it means that the implementation may take many years and will move more rapidly in some applications than in others.

A final point regarding crime scenes is appropriate here. Starting in the late 1990s, we saw the scope and size of crime scenes start to expand. Instead of processing a single room, a house, or a clandestine grave, scenes can now encompass (literally) city blocks or square miles. The terrorist attacks on September 11, 2001, illustrated this point. In effect, there were three scenes (New York, Pennsylvania, and Washington, DC) that had to be processed, and each of these scenes in turn covered very large areas. The Madrid (2004) and London (2005) bombings also fall into this category which is increasingly referred to as a **mass casualty event**. Such events require a forensic response even when there is no crime *per se*; consider the need to identify victims of such recent natural disasters as Hurricane Katrina, Hurricane Sandy, and the tsunamis in the Indian Ocean (2004) and Japan (2011). Hundreds or thousands of deaths require a forensic response for identification of the victims using many different techniques from DNA to dental records to fingerprints.

## 21.4 Death Investigation and Virtual Autopsy

Researchers in Europe are developing methods of performing autopsies without requiring a single cut. This method, referred to as **virtual autopsy ("virtopsy")**, takes advantage of advanced medical imaging techniques such as magnetic resonance imaging (MRI) and computer assisted tomography (CAT) scans to create a virtual image of a body from bones to soft tissue while minimizing the need for actual dissection. Not only is this a technical advantage, but there are many cases in which dissection is undesirable, such as for religious reasons. Another aspect of death investigation, at least in the United States, that is likely to change is the increasing use of medical examiner systems in lieu of coroners as the primary agents of death investigation. This is in part due to a growing realization that excellence in death investigation is best ensured using a medical examiner rather than a coroner, who may or may not have any medical training, depending on the jurisdiction. A limiting factor, however, is funding; establishing a new state system for medical examiners is expensive and may require an influx of federal funding to move forward.

## 21.5 Forensic Science Education

The advent of certification for academic forensic science education is a relatively recent development, beginning with the formation of FEPAC in 2004. Although new to forensic science, accreditation and certification of programs in other academic disciplines are well established, such as certification of chemistry degree programs by the American Chemical Society. The goal of accreditation is to ensure that programs provide a reasonable, rigorous, and viable curriculum for their students that will properly prepare them for work in a forensic science laboratory. This has become necessary as the popularity of forensic science degrees grew in the late 1990s and into the 2000s. Much, but certainly not all, of this interest can be traced to modern entertainment such as the *CSI* television series. To respond to the demand, some universities launched academic programs that lacked the strong central science component necessary for students to be competitive for forensic science jobs. FEPAC was launched by forensic scientists with the goal of ensuring that students emerging from an accredited forensic science degree program have the proper mix of science, math, lecture, and laboratory courses that are needed to obtain a forensic science position. As this edition went to press, over 38 undergraduate and graduate degree programs have FEPAC accreditation.

## Chapter Summary

There is always a risk in predicting the future of any scientific discipline, but the National Academy report provides us with a roadmap of the types of changes and developments that have been identified as critical for the future of forensic science. There is unlikely to be another breakthrough as significant as DNA typing in the near future, but we can certainly see the science and technology of forensic science moving forward a few paces behind the cutting edge. This lag time is essential to allow the law enforcement and legal communities time to study, evaluate, and determine the viability of these new methods in a legal setting.

## 21.6 Review Material

### 21.6.1 Key Terms and Concepts

Mass casualty event
Virtual autopsy ("virtopsy")

## 21.7 References and Further Reading

### 21.7.1 Books

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# Section IX Summary

This concludes our exploration of forensic science, ending with where it always starts—with human behavior and intention. Although human nature is unlikely to change in the near future, we have seen a glimpse of where forensic science appears to be heading. Scientifically and technically, we can expect instruments and automation to play an increasing role in day-to-day laboratory practice. At the crime scene itself, we are nearing a time when instrumentation may become more critical at the point of collection. As with all things forensic, we have to remember that it is not just the science that drives progress; rather, it is the judicial acceptance of that science that is required before any new practices become widespread. As we noted at the very beginning of the book, the forensic scientist serves two masters: the adversarial legal system and science where the scientific method reigns. It is that tension that makes forensic science challenging and unique.

## Integrative Questions

1. Discuss the timing of the *Daubert* decision and acceptance of DNA evidence in U.S. courts. Do you think it was coincidence? If not, why not?
2. There are some new techniques based on brain imaging that are being touted for use as lie detectors. Research a few and discuss. What are the advantages and dangers of such methods? Do you think the methods you read about could be admitted under a *Daubert* standard?
3. Discuss how evidence documented and collected at a crime scene is used to recreate behavior and intention.
4. As we have seen throughout this book, forensic science is rarely synonymous with “cutting edge” science. Why? Discuss from the perspective of the law and from the perspective of science.
5. Why is it so difficult to radically change the science in forensic science? What factors were at play in the story of DNA typing to allow it to move relatively quickly?
6. What are the current issues related to research in forensic science according to the NAS report? Why is this a concern?

# Appendix A

**Trigonometric Tables: Sine and Tangent Functions**

| Degrees | Sine | Tangent | Degrees | Sine | Tangent |
|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 36.0 | 0.5878 | 0.7265 |
| 1.0 | 0.0175 | 0.0175 | 37.0 | 0.6018 | 0.7536 |
| 2.0 | 0.0349 | 0.0349 | 38.0 | 0.6157 | 0.7813 |
| 3.0 | 0.0523 | 0.0524 | 39.0 | 0.6293 | 0.8098 |
| 4.0 | 0.0698 | 0.0699 | 40.0 | 0.6428 | 0.8391 |
| 5.0 | 0.0872 | 0.0875 | 41.0 | 0.6561 | 0.8693 |
| 6.0 | 0.1045 | 0.1051 | 42.0 | 0.6691 | 0.9004 |
| 7.0 | 0.1219 | 0.1228 | 43.0 | 0.6820 | 0.9325 |
| 8.0 | 0.1392 | 0.1405 | 44.0 | 0.6947 | 0.9657 |
| 9.0 | 0.1564 | 0.1584 | 45.0 | 0.7071 | 1.000 |
| 10.0 | 0.1736 | 0.1763 | 46.0 | 0.7193 | 1.036 |
| 11.0 | 0.1908 | 0.1944 | 47.0 | 0.7314 | 1.072 |
| 12.0 | 0.2079 | 0.2126 | 48.0 | 0.7431 | 1.111 |
| 13.0 | 0.2250 | 0.2309 | 49.0 | 0.7547 | 1.150 |
| 14.0 | 0.2419 | 0.2493 | 50.0 | 0.7660 | 1.192 |
| 15.0 | 0.2588 | 0.2679 | 51.0 | 0.7771 | 1.235 |
| 16.0 | 0.2756 | 0.2867 | 52.0 | 0.7880 | 1.280 |
| 17.0 | 0.2924 | 0.3057 | 53.0 | 0.7986 | 1.327 |
| 18.0 | 0.3090 | 0.3249 | 54.0 | 0.8090 | 1.376 |
| 19.0 | 0.3256 | 0.3443 | 55.0 | 0.8192 | 1.428 |
| 20.0 | 0.3420 | 0.3640 | 56.0 | 0.8290 | 1.483 |
| 21.0 | 0.3584 | 0.3839 | 57.0 | 0.8387 | 1.540 |
| 22.0 | 0.3746 | 0.4040 | 58.0 | 0.8480 | 1.600 |
| 23.0 | 0.3907 | 0.4245 | 59.0 | 0.8572 | 1.664 |
| 24.0 | 0.4067 | 0.4452 | 60.0 | 0.8660 | 1.732 |
| 25.0 | 0.4226 | 0.4663 | 61.0 | 0.8746 | 1.804 |
| 26.0 | 0.4384 | 0.4877 | 62.0 | 0.8829 | 1.881 |
| 27.0 | 0.4540 | 0.5095 | 63.0 | 0.8910 | 1.963 |
| 28.0 | 0.4695 | 0.5317 | 64.0 | 0.8988 | 2.050 |
| 29.0 | 0.4848 | 0.5543 | 65.0 | 0.9063 | 2.145 |
| 30.0 | 0.5000 | 0.5774 | 66.0 | 0.9135 | 2.246 |
| 31.0 | 0.5150 | 0.6009 | 67.0 | 0.9205 | 2.356 |
| 32.0 | 0.5299 | 0.6249 | 68.0 | 0.9272 | 2.475 |
| 33.0 | 0.5446 | 0.6494 | 69.0 | 0.9336 | 2.605 |
| 34.0 | 0.5592 | 0.6745 | 70.0 | 0.9397 | 2.748 |
| 35.0 | 0.5736 | 0.7002 | 71.0 | 0.9455 | 2.904 |

**Trigonometric Tables: Sine and Tangent Functions (cont.)**

| | | | | | |
|---|---|---|---|---|---|
| 72.0 | 0.9511 | 3.078 | 82.0 | 0.9903 | 7.115 |
| 73.0 | 0.9563 | 3.271 | 83.0 | 0.9925 | 8.144 |
| 74.0 | 0.9613 | 3.487 | 84.0 | 0.9945 | 9.514 |
| 75.0 | 0.9659 | 3.732 | 85.0 | 0.9962 | 11.43 |
| 76.0 | 0.9703 | 4.011 | 86.0 | 0.9976 | 14.30 |
| 77.0 | 0.9744 | 4.332 | 87.0 | 0.9986 | 19.08 |
| 78.0 | 0.9781 | 4.705 | 88.0 | 0.9994 | 28.64 |
| 79.0 | 0.9816 | 5.145 | 89.0 | 0.9998 | 57.29 |
| 80.0 | 0.9848 | 5.671 | 90.0 | 1.000 | 0.000 |
| 81.0 | 0.9877 | 6.314 | | | |

# Appendix B

**ABO blood groups:** Human antigenic system designating the blood groups A, B, AB, and O.
**Abraded/abrasion:** A scraping type of wound.
**Absorption elution:** A method for performing ABO blood typing in stains.
**Accelerant:** Agent, often an ignitable liquid, that acts to initiate a fire or increase its rate of spread.
**Accident avoidance strategy:** The presumption that certain parties involved in an accident traveled at the legal speed and performed reasonably in all their actions, including braking, turning, and accelerating.
**Accident reconstruction:** The use of evidence to reconstruct the events involved in an accident.
**Accidental characteristics:** A characteristic of an item that was obtained through some process other than at the time of production.
**Accreditation:** Endorsement of policies and procedures by a recognized accrediting body or organization.
**ACE-V:** Four steps (analysis, comparison, evaluation, and verification) followed to evaluate and identify a latent fingerprint according to Ashbaugh; accepted widely in the latent fingerprint examiner community. Sometimes pronounced ace vee.
**Acid phosphatase:** Enzyme group that catalyzes the hydrolysis of certain organic phosphates. Seminal acid phosphatase (SAP) is produced in the prostate gland and serves as a presumptive test for semen.
***Actus reus*:** Literally, the guilty act.
**Adiabatic flame temperature:** Theoretically, the highest temperature at which a fuel can burn; it is derived mathematically. Because certain combustion products tend to disassociate at high temperatures, the true maximum burning temperature, even under ideal conditions, is usually slightly lower.
**ADME:** The process by which a drug moves through the body: adsorption, distribution, metabolism, and excretion.
**Admissible evidence:** Evidence that is determined to be admitted into evidence and be considered in rendering the decision.
**Adversarial system:** A system in which decisions are rendered based on the merit of two opposing arguments. The legal system in the United States is an adversarial system.
**AFIS:** Automated Fingerprint Identification Systems.
**Agenesis:** Failure of a tooth to form.
**Agglutinins:** Antibodies in the blood that bind with agglutinogens on the surface of red blood cells.
**Agglutinogen:** Antigen on the surface of red blood cells that bind with agglutinins.
**Algor mortis:** The postmortem cooling of the body.
**Alkaloids:** Substance formed in the plant tissues and in the bodies of animals. Morphine and codeine are alkaloids of opium.
**Allele:** One of two alternative forms of a gene occurring at a locus on homologous chromosomes.
**Allometry:** The relationship between the size of a body part and the size of the entire body.
**alpha-Amylase:** An enzyme found in saliva that is the basis of presumptive tests for that body fluid.
**Alteration:** Change of a written or printed portion of a document, usually accomplished after obliterating or masking the original information.
**Alternative light source (ALS):** A light source other than daylight or indoor lighting; used to visualize materials or stains that are not otherwise visible.

**American Board of Forensic Anthropology:** The organization that certifies forensic anthropologists for practice at the post-doctoral level.

**American Society of Testing and Materials (ASTM):** A group that establishes national and international standard practices for procedures and analyses.

**Amorphous:** No organized molecular structure.

**Amphetamines:** A controlled substance that, along with its analogs such as methamphetamine, creates an excitatory condition (stimulation), state of wakefulness, and euphoria.

**Amplicons:** Product of the amplification of DNA or RNA.

**Amylases:** Enzymes that are used in the conversion of starches into less complex sugars.

**Anagen phase:** The growth period of hair.

**Analyzer:** Polarizing filter placed near the light source in a polarizing light microscope.

**Ancestry:** The genetic relationship of an individual to one or more particular geographic populations.

**Angle of acceptance (AA):** Maximum angle between light waves that an objective lens (OBJ) can collect.

**Angle of attack:** The angle at which a tool is held when making a mark.

**Angle of impact:** Acute or internal angle formed by the direction of a blood drop and the plane of the surface it strikes.

**Anisotropic:** A sample that splits polarized light into two perpendicular directions.

**Annealing:** Pairing of complementary strands of dot-blot DNA analysis (DQ-alpha and amplitype PM).

**Anorexic:** Appetite suppressant.

**Antemortem trauma:** Injury to a body that occurs during life.

**Anthropometry:** A system of criminal identification based on a series of measurements of physical features; pioneered by Bertillion.

**Antibody:** An immunoglobulin molecule with specific receptor sites formed in response to an antigen.

**Antigen:** A substance that can stimulate an immune response when introduced into a host.

**Apocrine:** A type of sweat gland.

**Arch:** One of three basic fingerprint patterns.

**Area of convergence:** The area in space where the trajectories of blood converge; related to point of origin. See also point of convergence.

**Area of origin:** Fire-related area in space where a fire started or where blood that resulted in a stain originated.

**Arterial spurting:** Bloodstain patterns resulting from blood exiting the body under pressure from a breached artery.

**Asphyxia:** A death that is caused by interference with the oxygenation of the brain.

**Association/associative evidence:** Establishment of a relationship between objects (evidence and other items) through examination; evidence that establishes that relationship.

**Assault rifle:** Automatic weapons that fire a reduced-charge rifle cartridge.

**Automatic weapons:** Firearm that continues to fire as long as its trigger is depressed and ammunition is available.

**Autopsy:** A dissection of a body conducted to determine the cause and manner of death.

**Azoospermia:** Semen that does not contain sperm cells.

**Azostix®:** Commercial test strip for detecting urea in blood; measures the shift in pH resulting when urea is catalyzed to ammonia and carbon dioxide by urease; used forensically to detect urine.

**Back draft:** A type of explosive ignition that occurs when a smoldering fire is exposed to a fresh supply of oxygen.

**Backscatter :** Blood directed back toward the source of energy or force that caused the spatter. Backspatter is often associated with entrance gunshot wounds.

**Backscattered electrons (BSEs):** In scanning electron microscopy, higher energy electrons that are elastically scattered from the sample.

**Backspatter:** Impact spatter associated with an exit wound.

**Ball powder:** Smokeless powder manufactured by extruding nitrocellulose lacquer into hot water.

**Base pairs (bp) :** Combination of two nucleotides (A and T or G and C) held together by weak hydrogen bonds. The DNA double helix is formed when base pair nucleotides in the DNA strands are connected by these bonds. The DNA strands are held together by strong chemical bonds. The two halves of the molecule are held by the weaker hydrogen bonds. The double helix may be visualized as two strips of Velcro®. Weak bonds hold it together and the two strips are difficult to break or rip.

**Becké line:** A method utilized to determine the refractive index of materials, such as glass.

**Beginning stroke:** Initial stroke of a letter.

**Bending fracture:** A fracture that results from a material becoming bent.

**Benzidine:** A reagent that was once widely used in a presumptive test for blood.

**Bias belted:** Tires that have plies running beneath the tread at an angle (bias) across the tire but with the addition of belts beneath the tread surface.

**Bifurcation:** A fingerprint pattern in which a ridge splits into two.

**Bioaccumulation:** The process of substances building up over time in an organism.

**Biofluids:** Blood, urine, bile, etc.; fluids obtained from the body.

**Biological anthropology:** One of the four major subfields of anthropology, focusing on the biological basis of human form, behavior, and variation.

**Biological profile:** A description of human remains that includes the probable sex, age, ancestry, and stature, as well as any observed pathology or anomalies.

**Biological sex:** The designation of male or female based on genetic characteristics.

**Biometrics:** Science and technology of using individually variable features of the human body for identification.

**Birefringence:** Having two or more indices of refraction. When placed between polarizing filters, birefringent materials exhibit bands of color. The specific colors exhibited when white (polychromatic) light is used as the illuminant are determined by the differences in the indices of refraction and the thickness of the birefringent material.

**Bitstream data copy:** Duplicates all data in a cluster, including anything that is in the slack space and unallocated space where digital forensic evidence may be hidden. A copy may not retain digital evidence.

**Blow flies:** Flies that often are the first to arrive at a body after death; a member of the Diptera family.

**Blowback:** An operating principle of automatic and semiautomatic firearms. The fired cartridge blows back against the breechblock, forcing it to the rear and extracting and ejecting the expended cartridge casing. Also describes the blowing back of blood and other tissue onto a firearm or a shooter from a near-contact or contact shot.

**Blunt start:** Lack of one continuous movement of a writing instrument as it touches paper in the initial writing stroke.

**Blunt trauma/blunt force trauma:** A non-penetrating injury that results from force applied to the body.

**Bolt action:** A type of action used in rifles.

**Bolt-face signatures:** Marking embossed on a cartridge primer (or base of cartridge) by a breechblock or bolt.

**Bone densitometry:** Method of measuring bone density.

**Bone density:** A measure of the concentration of bone mineral including the fracture risk.

**Botanical examinations:** Study of various plant structures, such as roots, stems, branches, leaves, fruits, or flowers, that may be used to determine time and season of death as well as possible prior location of remains.

**BPA:** Bloodstain pattern analysis.

**Breechblock:** The metal block in an automatic weapon that is at the end of the barrel opposite from where the bullet exits.

**Broaching:** A method of rifling a barrel to impart lands and grooves.

**Bullet wipe:** Soot, lubricant, or other material wiped from the surface of a bullet onto skin or other surfaces penetrated by the bullet.

**Caliber:** Diameter of a circle tangent with the tops of the lands of the rifling. Caliber is a nominal measurement; actual bore diameter may be different from the designated caliber.

**Callus:** A scar of bone material that forms around a fracture site.

**Cannabinoids:** A term applied to marijuana and parts of the plant *Cannabis sativa* in which tetrahydrocannabinol (THC) is the active agent.

**Cannelures:** Knurled grooves on a bullet meant for lubricant.

**Capillary electrophoresis:** An instrumental technique that is used in DNA typing.

**Carbon monoxide (CO):** A highly toxic gas that is formed as a product of combustion.

**Carboxyhemoglobin:** Hemoglobin in which the oxygen has been replaced by carbon monoxide (CO).

**Carboxymyoglobin:** The form of myoglobin (a protein) that results when it binds with carbon monoxide.

**Carrier gas:** The mobile phase in gas chromatography (GC).

**Carrion:** The decaying flesh of an animal.

**Cartridge:** The circular metal container for propellant; contains the firing pin and also the bullet when loaded.

**Castoff patterns:** Bloodstain pattern created when blood is released or thrown from a blood-bearing object in motion.

**Catagen stage:** The intermediate or transition phase of hair growth.

**Cause of death:** Disease or injury that initiates the lethal train of events leading to death—for example, coronary heart disease or a gunshot wound of the heart.

**Centerfire cartridges:** Firearm cartridge in which the primer compound is contained in a centrally positioned primer cap.

**Central pocket whorl:** One of several types of whorl patterns in fingerprints.

**Certification:** Official recognition of professional development.

**Chain of custody:** The documented process the evidence goes through from the point of gathering to the final presentation in court; intended to ensure that the evidence has not been tampered with or altered.

**Chemical color tests:** Chemical reactions producing colors when compounds or classes of compounds are brought into contact with various chemical reagents.

**Chemical trauma:** Injury produced by exposure to or ingestion of a chemical.

**Chemiluminescence:** The process by which light is emitted as a product of a chemical reaction.

**Choke:** Constriction in the muzzle of a shotgun intended to concentrate the shot pattern.

**Chromogenic substance:** A compound which, when oxidized, displays a characteristic color.

**Circumstantial evidence:** Evidence requiring the trier of fact to infer certain events—for example, linking a defendant to a crime scene (and ultimately to the crime) via DNA, hair, fiber, glass, footprint, fingerprint, or ballistics evidence.

**Civil law:** A body of law that governs non-criminal cases; involves disputes between two parties such as two companies disputing a patent.

**Clandestine drug laboratories:** Illicit location that manufactures controlled substances.

**Class-characteristic evidence:** Features of evidence that assist in initial classification; for example, a fingerprint pattern of a whorl or an arch would be considered a class characteristic.

**Class characteristics:** A feature of an item that is unique to a group of items or information in a nonindividual context about some aspect physical evidence such as a shoe print or tire impression.

**Closed-circuit television (CCTV):** A system of cameras installed primarily for surveillance purposes.

**Clot:** A coagulated mass of blood.

**Cocaine:** A controlled substance derived from the erythroxylin cocoa plant that creates an excitatory condition (stimulation), state of wakefulness, and euphoria.
**CODIS:** Combined DNA Index System.
**Colin Pitchfork:** The first man convicted of a crime as a result of DNA testing.
**Colorimeter:** A device that is used to characterize color using a spectrometer.
**Colorimetric testing:** Testing in which a change or production of color is used to screen for compounds.
**Combustible liquid:** A liquid that has a fire point greater than 100°F.
**Comparison microscope:** Two microscopes linked by an optical bridge so the observer can simultaneously view two independent images in one field each from a separate objective.
**Competency:** Determination by the state as to a person's ability to stand trial.
**Compression tool mark:** A type of tool mark made by pressure.
**Concentric cracks:** Fractures that appear to circle around the point of impact.
**Conchoidal lines:** Edge characteristics of glass fractures. They are stress marks shaped like arches that are perpendicular to one glass surface and curved nearly parallel to the opposite surface. The perpendicular surface faces the side where the crack originated.
**Conduction:** The transfer of heat via direct contact.
**Confirmatory test:** A test used to confirm the results of preliminary analysis or presumptive tests.
**Congenital anomaly:** Anatomical variants that are present from birth.
**Connecting strokes:** Joining the ending stroke of one letter to the beginning stroke of another letter.
**Conservation of energy:** The first law of thermodynamics; energy is neither created nor destroyed.
**Conservation of momentum:** In the context of accident reconstruction, the net momentum of the vehicles involved in an accident just prior to the collision is equal to the net momentum just after the collision.
**Contraband materials:** In forensic toxicology and drug testing facilities, this refers to suspected controlled substances.
**Control (comparison) samples:** Control A test performed in parallel with an experimental procedure and designed to yield predictable results that confirm the reliability of the experimental results.
**Controlled Substances Act (CSA):** Legislation in the United States that defines illegal drugs and classifies them by Schedules.
**Contusion ring:** Bruising at the edges of a gunshot wound caused by penetration of the skin by a bullet.
**Contusion:** A bruise; bleeding beneath the surface of the skin; an accumulation of blood in the tissues outside the blood vessels.
**Convection:** Transfer of heat by a circulating medium such as air or water.
**Copybook:** Instruction manual for learning penmanship.
**Core:** The center of a whorl pattern in a fingerprint.
**Coroner:** A court official in medieval England whose duties included investigating sudden and unexpected deaths and deaths from injury; in the United States, an elected official with death investigation duties.
**Cortex:** The main body of hair containing protein fibrils, pigment, cortical fusi, and ovoid bodies.
**Cortical bone:** External layer of bone, characteristically dense and having a relatively smooth surface, as contrasted with inner, spongy or trabecular bone.
**Cortical fusi:** Microscopic air pockets or vacuoles within the cortex of hair.
**Cranium:** That part of the skull that includes the brain case and the face, but not the lower jaw.
**Creatinine:** Component of urine that reacts with picric acid to form creatinine picrate, a detectable color product.
**Crime scene integrity:** The process and procedures used to keep the crime scene in as close to original condition as possible; practices used to prevent altering or compromising a scene.

**Crime scene management:** Teamwork approach of investigators and crime scene personnel that successfully resolves a case.
**Crime scene mapping/forensic mapping:** Using techniques associated with surveying to obtain data that can be used to generate a three-dimensional rendering and record of the scene.
**Crime scene reconstruction:** Analysis and reconstruction of a crime scene that logically links a detailed series of scientific explanations to provide an understanding of the sequence of events.
**Crime scene security:** Practices used to secure a crime scene and to keep unauthorized persons away to protect the scene integrity.
**Crime scene sketch:** A rough drawing used to document a crime scene.
**Crime scene staging:** A scene that has been altered to send the investigation off course and away from the offender.
**Crime scene survey:** A rapid initial study of the crime scene or areas suspected to be a crime scene.
**Criminal law:** The body of law that applies to criminal acts; involves a government entity such as a state.
**Criminalistics:** Application of physical sciences to criminal investigation.
**Cross-examination:** The questioning of a witness by the party that did not call the witness. When an expert testifies for the prosecution in a criminal case, the defense would cross-examine.
**Crossed polars:** Condition in polarized light microscopy in which the analyzer and polarizer are perpendicular to each other.
**Crystal tests/microcrystal tests:** A type of presumptive test in which a positive result is the formation of a solid crystalline substance.
**Cut rifling:** A method of rifling a barrel to impart lands and grooves.
**Cuticle:** Outermost portion of hair.
**Cutting agent:** A substance added to an illicit drug to reduce the concentration.
**Cutting tool mark:** A type of tool mark made by cutting.
**Cyanide (CN):** A highly toxic chemical, especially in the form of gas (hydrogen cyanide).
**Cyanoacrylate fuming:** Important fuming method for the visualization of latent fingerprints. See also Super Glue®.
**Cyanomethemoglobin:** A complex of cyanide and methemoglobin; used to treat cyanide poisoning.
***Daubert* decision:** A case decision in 1993 that provided guidance for judges in admitting evidence; often referred to as the *gatekeeper* decision.
***Daubert* test:** A standard for determining the reliability of scientific expert testimony in court currently adopted by many jurisdictions. Five factors are utilized to assess the scientific theory or technique: testing of theory, use of standards and controls, peer review, error rate, and acceptability in the relevant scientific community.
***Daubert* trilogy:** Three cases decided in the 1990s that are used by federal and other courts to determine the admissibility of scientific evidence.
**Dead loads:** In a building, weights that do not change significantly, such as the weight of the floors, walls, supports, and roof.
**Debris method:** An examination of debris on the ground at an accident scene, such as headlight glass, turn signal lens parts, and other parts that were damaged on the vehicle.
**Deciduous dentition:** Dentition that develops in a child and is replaced by permanent dentition.
**Decomposition:** Breakdown of tissues in a body after death, including enzymatic chemical breakdown (autolysis) and breakdown by bacterial action (putrefaction).
**Defendant:** The suspect or accused in a criminal case or the person who is alleged to have caused the injury to the plaintiff.
**Delta:** Part of a whorl pattern in fingerprints.
**Delusterant:** A substance added to the surface of fibers to cause light scattering and a less shiny appearance.

**Denaturation:** Loss of the natural configuration of a molecule through heat, chemical treatment, or pH change.

**Dental stone:** Gypsum product, similar to plaster of Paris. Its hardness and durability make it a superior product for casting footwear or tire impressions.

**Depressants:** Substances that depress the central nervous system and cause symptoms such as slowed heart rate and breathing.

**Depth of field (DF):** Total distance (height) above and below the point of focus that also appears clearly focused. The DF decreases with increase of numerical aperture (NA) and magnification.

**Deterrents:** Compounds added to propellants to slow the burning rate.

**Development:** A process applied to a latent fingerprint to make it visible.

**DFO:** A chemical fingerprint developer (1,8-diazafluoren-9-one).

**Diaphysis:** Bone growth center that forms the shaft of a long bone.

**Diatoms:** Small unicellular organisms found in most fresh and salt waters in the world.

**Digital evidence:** Evidence in digital form such as the contents of a hard disk drive, a DVD, or a memory stick.

**Diminished capacity:** An offender who could not or did not form the specific intent or could not act in a knowing and purposeful manner.

**Direct evidence:** Information that establishes a fact directly, without the need for further inference—for example, an eyewitness' testimony that the defendant fired the fatal shot.

**Direct examination:** Questioning of a witness by the party that called that witness. If an expert is called by the prosecution, the prosecution begins the questioning by direct examination.

**Directionality:** Parameter that indicates the direction the blood was traveling when it impacted the target surface. Directionality of flight can usually be established from the geometric shape of the bloodstain.

**Disarticulated:** Separation of bones at the joint.

**Disguised writing:** Alteration of handwriting for the purpose of concealment.

**Disorganized offender:** Offender that commits crime impulsively with little or no planning. The perpetrator's lack of control over his victim and himself is apparent from the evidence.

**Dissimulation:** A conscious and deliberate attempt to minimize or deny symptoms of a mental disorder.

**Distal end:** The tip of hair that is away from the root.

**Distance determination:** Process of estimating the distance from a shooter to a person who was shot.

**Distance gunshot wound:** Firearm wound that lacks stippling, smoke, or soot. It generally indicates a distance of 1 meter or more from the skin to the gun muzzle at the time of discharge.

**DNA polymerases:** Enzymes that break the linkage within the double helix of DNA.

**Domino effect:** A structural failure that proceeds in an orderly fashion.

**Dot:** The smallest component of printer output. Resolution is expressed in dots per inch or pixels per inch.

**DOT number:** A number that appears on every tire that shows where and when the tire was made. The U.S. Department of Transportation has required such numbers since 1972.

**Double-base powder:** Powder in which nitrocellulose and nitroglycerin are the energetic materials.

**Double-loop whorl:** One of several types of whorl patterns in fingerprints.

**Double-variation method:** A method of determining refractive index that employs a heating stage to maintain oil temperature; a monochrometer is employed to determine the match wavelength.

**Drip patterns:** Bloodstain pattern resulting from blood dripping into blood.

**Drug Enforcement Administration (DEA):** The U.S. government agency responsible for regulation of controlled drugs.

**Dry origin impression:** Impression that contains no significant moisture from itself or its substrate when made.

**Dual tire assembly:** Wheel assembly with two tires mounted next to one another on each side of an axle.

**DUI:** Driving under the influence of an intoxicating substance.

**Duquenois–Levine test:** Chemical color test used to confirm the presence of cannabinoids in plant material.

**Durometer:** A device for measuring the hardness of a tire or similar product.

**Dynamic loads:** Loads or forces that change and usually produce motion.

**Eccrine:** A type of sweat gland.

**Ejector:** Device in an automatic or semiautomatic firearm that wrests the expended cartridge from the extractor and ejects it from the firearm; in a revolver, it ejects cartridges from the chambers in the cylinder.

**Elastic collision:** Collision between two bodies in which the deformation of each body is directly proportional to the applied force (Hooke's law).

**Electrochemical etching:** Rifling method in which the grooves of the rifling are produced by an electrochemical process.

**Electronic data collection (EDC):** Refers to techniques used to determine distances, elevations, etc. in forensic mapping.

**Electronic evidence:** See digital evidence.

**Elimination footwear:** Shoes collected from medical personnel, police officers, or other innocent persons who, in addition to the suspect, could possibly have left the recovered footwear impressions.

**Elimination vehicles:** Tires from vehicles, including emergency vehicles, that may have inadvertently left tire impressions in the crime scene area.

**Enamel:** The outer covering of the crown of the tooth.

**Ending stroke:** Terminal stroke of a letter.

**Energy-dispersive x-ray spectroscopy (EDS):** A type of spectrometry used in combination with scanning electron microscopy that assists in identification of chemical elements.

**Enhancement:** Rendering an impression more visible through physical, photographic, chemical, or digital methods.

**Entomotoxicology:** The study of drugs, poisons, and metabolites found in insects.

**Enzyme systems:** A form of hemoglobin that is exploited in some microcrystal tests.

**Epiphyseal union:** Fusion of the bone growth center located at the end of a long bone (the epiphysis) with the bone growth center that forms the central shaft (diaphysis).

**Epiphysis:** Bone growth center that forms the end or part of the end of a long bone, or the margin of some flat bones. The epiphysis is originally connected by cartilage, which ultimately becomes bone.

**Equifinality:** Similar result from two different processes. In taphonomy, different agents may produce modifications to bone that cannot be differentiated from one another.

**Equivocal death:** Manner of death (homicide, suicide, accident) remains undetermined after a complete investigation.

**Erythrocytes:** Red blood cells.

**Examination-quality photography:** Photographs taken by a camera held directly over evidence, such as a shoe or tire impression, that will be useful during a detailed examination of that evidence.

**Exculpatory evidence:** Evidence that tends to exonerate the accused party.

**Exemplar:** (1) Example or representative item usually in undamaged or less damaged condition to which a damaged item can be compared. (2) Writing that is produced upon request.

**Expirated bloodstain patterns:** Patterns created from blood propelled from the nose, mouth, or a wound as a result of air pressure or air flow.

**Explosion:** Sudden conversion of potential energy (often chemical) to kinetic energy accompanied by physical destruction of the container or structure via a high-pressure wave front.

**Exsanguination:** Death after a significant amount (usually half or more) of blood is lost; bleeding to death.
**Extenders:** Materials added to paints to thin out the mixture.
**Extracellular fluid:** Fluid found outside of cells such as blood.
**Extraction:** Separation of the compound of interest from the rest of the sample.
**Extractor:** Component of a firearm that pulls an expended cartridge from the firing chamber.
**Extruded powder:** Smokeless powder manufactured by extrusion of nitrocellulose dough through a perforated steel plate. A sharp knife rotating against the plate cuts specified lengths of extruded dough.
**Eyepiece lens (EP):** In a microscope, the lens next to the eye.
**Facial approximation:** Modeling the appearance of a face based on the skeletal structure.
**Fallabilism:** Awareness of what is not known and the humility to acknowledge the possibility of making mistakes.
**False negative:** An incorrect result on a test in which the test should have been negative but gave a positive result.
**False positive:** An incorrect result on a test in which the test should have been positive but gave a negative result.
**Fatigue-type fracture:** A fracture that results from a material becoming "tired" due to repeated applications of dynamic loads. The material fractures or fails at a strength level significantly less than it would fracture or fail if only static loads were applied.
**Federal Rules of Evidence:** Federal guidelines designed to guide federal courts in determining if scientific evidence is admissible.
**Felony:** In criminal cases, the more serious type of offense.
**Finder-of-fact:** In a legal proceeding, the party making the decision; also called *trier of fact*.
**Fire:** A rapid oxidation process with the evolution of heat and light.
**Fire load:** Amount of material that can burn. The average fire load of a building is usually stated in British thermal units (BTUs) per square foot to enable comparison of the fire-sustaining potential of one building to that of another.
**Fire patterns:** Marks left by fire, smoke, and soot on structures and devices. Several characteristic patterns help identify the relationship and orientation of the fire to the structure: horizontal patterns, plumes, V-shaped patterns, and saddle burns.
**Fire point:** The temperature at which a liquid produces vapors that will sustain combustion.
**Firing pin impressions:** An impression made on a primer by a firing pin.
**First instar :** First-stage fly larvae that cannot penetrate skin and must subsist on liquid protein.
**First responder:** First person arriving at a crime scene; usually a law enforcement officer or other emergency personnel.
**Flammable liquid:** A liquid that has a fire point less than 100°F.
**Flanking region:** Region just adjacent to a region of interest, a gene, a repeat, or any other sequence.
**Flash suppressants:** Compounds added to propellants to minimize flame and flash.
**Flashpoint:** The temperature at which a liquid gives off sufficient vapors to form an ignitable mixture at its surface.
**Flow patterns:** Change in the shape and direction of a wet bloodstain due to the influence of gravity or movement.
**Fluorescein:** A presumptive test for blood based on the emission of light.
**Forcing cone:** Flaring at the breech end of the barrel of a revolver. It serves to guide the bullet into the rifling.
**Forensic anthropology:** Profession that utilizes the knowledge and skills of anthropology, particularly physical/biological anthropology archaeology, to address forensic problems.
**Forensic archaeology:** Profession that utilizes the knowledge and skills of archaeology to address forensic problems.

**Forensic evidence:** Broadly, physical or opinion evidence that is generated by a forensic practitioner or one hired in a forensic role.
**Forensic pathologist:** A medical doctor who studies pathology in the context of death investigation.
**Forensic pathology:** The specialty of medicine and subspecialty of pathology dealing with investigating the causes of sudden and unexpected deaths.
**Forensic taphonomy:** The scientific study of postmortem processes applied to forensic problems.
**Forward spatter:** Blood that travels in the same direction as the source of energy or force; often associated with exit gunshot wounds.
**Frangible bullets:** Bullets that break apart easily.
**Frass:** Insect feces.
**Freehand simulations:** Attempt to copy or draw a signature without the use of mechanical aids.
**Frequency:** How many wavefronts pass by a location per second; higher energy electromagnetic energy has a higher frequency.
**Friction ridge skin:** Skin on the soles of the feet, palms of the hands, and fingers in humans and some primates that forms ridges and valleys. Friction ridge skin forms classifiable patterns on the end joints of the fingers.
**Frye decision:** A standard applied in some jurisdictions to the admissibility of scientific theory and method in court based upon the acceptance of the theory and method by the scientific community.
**Full metal jacket:** A bullet in which the lead is completely encased in another metal such as copper.
**Furrows:** The valleys between ridges in fingerprint patterns.
**Gait analysis/gait characteristics:** Measurement of stride.
**Gas chromatography (GC):** Gas flowing through a coated tube separates compounds by their size, weight, and chemical reactivity with the coating of the tube or column.
**Gas piston:** One of three ways in which an automatic or semiautomatic weapon can function.
**Gatekeeper:** The term used in relationship to the *Daubert* decision; the judge is designated as the one who determines admissibility under these rules and is thus the gatekeeper.
**Gauge:** The method of designating the diameter of a shotgun barrel. It equals the number of round lead balls of the diameter of the interior of the shotgun barrel required to weigh 1 pound.
**GC-MS:** Acronym for gas chromatography coupled with mass spectrometry.
**Gender:** Sexual orientation that is individually or socially assigned.
**General acceptance:** A shorthand description of the *Frye* decision which dictated that scientific evidence is admissible if it has achieved general acceptance by the relevant scientific community.
**Generalist :** In forensic science, an analyst that is qualified to work in several disciplines.
**Genetic marker system:** Systems in the body that are directed by heredity and thus can be used forensically. The ABO blood group system is an example.
**Glowing combustion:** Occurs after flame combustion ends.
**Grabbers:** Mechanical "fingers" in a copy machine or printer that draw the paper through the machine.
**Grand jury:** A special type of jury that is empowered to decide if the evidence against a defendant warrants proceeding to the next step.
**Gray ring:** See bullet wipe.
**Green tire:** Unfinished tire that has all its components but has not yet been molded. It has no tread or sidewall design.
**Griess test:** A color test that detects nitrites.
**GRIM (glass refractive index measurement):** An automated method for determining the refractive index of glass.
**Grooves:** Void areas that run around and across a tire between the design elements; recessed areas of rifling.
**Gunshot residue (GSR):** Residue from the primer that is produced when a gun is fired.

**Hammer forging:** Rifling method in which a barrel blank is hammered down over a mandrel. This method is used to make polygonal rifling.
**Hammer:** In a weapon, the metal that is pulled back to cock it and prepare for firing.
**Hashish:** The resin from marijuana that has been isolated from the plant material.
**Headstamp:** The base of a cartridge and shotshell.
**Height ratio:** Ratios of heights of letters compared to others.
**Helixometer:** A device used to determine the number and lands and grooves and their direction and degree of twist.
**Hemastix®:** A commercial test strip that can be used as a presumptive test for blood. The strips are designed to detect blood in urine but work well in forensic applications.
**Hematin:** A derivative of hemoglobin.
**Hematoma:** A tumor of blood caused by leakage from damaged blood vessels; it contains enough blood to form a blood-filled space.
**Hemoglobin:** The oxygen-carrying substance in blood.
**Henry system:** Classification of 10-fingerprint cards so that they can be stored in large files. The system has been rendered largely obsolete by AFIS, but was widely used in the United States and the United Kingdom.
**Heterozygosity:** Two different alleles at a specific genetic locus.
**High explosive:** An explosive that is generally stable and that is detonated by a primary explosive. A high explosive detonates rapidly as compared to low explosives.
**High-order explosion:** Explosion characterized by a rapid pressure increase relative to low-order explosion.
**Hinge lifters:** One-piece fingerprint lifters.
**Hollow-point bullet:** A bullet with a hollowed-out nose; it is designed to mushroom on contact, causing more tissue damage than a standard bullet.
**Homeostasis:** Maintenance of a constant body temperature.
**Homozygous:** Refers to both alleles being the same at a specific genetic locus.
**Hook cutting:** Rifling tool with a raised cutting edge used to cut one groove of rifling at a time.
**Hooke's law:** Within certain limits, the deformation of a material is directly proportional to the applied force causing the deformation.
**Hyoid bone:** A small horseshoe-shaped bone found in the neck near the base of the jaw.
**Hyperthermia:** A body temperature that is dangerously higher than normal.
**Hypervariable regions:** Locus with many alleles, especially those whose variation is due to variable numbers of tandem repeats.
**Hypothermia:** A body temperature that is dangerously lower than normal.
**IABPA:** International Association of Bloodstain Pattern Analysts.
**IAFIS:** Integrated Automated Fingerprint Identification System.
**Identification evidence:** Evidence that provides positive identification of the source; this term is falling out of favor.
**Immersion method:** Determination of a refractive index based on submersion of a sample in a liquid.
**Immunoassay:** Tests utilizing antibodies that react with a drug or substance that recognizes the antibody.
**Immunological reactions:** Reactions between an antigen and an antibody.
**Impact site:** Point on a bloody object or body that receives a blow; may also refer to an area struck by blood in motion. The term impact site is used interchangeably with point of origin.
**Incendiary fire:** Fire intentionally caused by human activity.
**Incised wounds:** Injury produced by a sharp instrument and characterized by lack of surface abrasion and absence of bridging vessels, nerves, and smooth margins.
**Inculpatory evidence:** Evidence that tends to implicate the accused party.

**Indented writing:** Writing on a page that is captured on the second sheet of paper below the one that contains the original writing.

**Individual characteristics:** Feature that is unique to a specific item; information in a specific context about some aspect of a crime scene. Examples include a print left by a shoe consistent in all respects to the defendant's shoe, a hair consistent in all respects to a sample of hair from a Caucasian female, or handwriting features attributable to a particular person. See also minutiae.

**Individualization:** Establishment of uniqueness of an item through examination and experimentation, showing that no other item is exactly like the one in question. An example would be establishing a match by comparing features on a fingerprint to a known print. The adjective form is individualistic.

**Inductively coupled plasma mass spectrometry (ICP-MS):** A form of mass spectrometry used to detect inorganic materials and metals.

**Inframammary incision:** The initial incision of an autopsy, the "Y"-shaped incision from shoulders to pubic area.

**Infrared (IR) spectrophotometry:** Use of the absorption of infrared radiation to produce a chemical fingerprint of a substance; also referred to as *IR spectroscopy*.

**Insanity:** Generally, a mental state in which the individual could not or did not know what he or she was doing or that what he or she was doing was wrong.

**Interference colors:** Interaction that occurs when two separate light rays are recombined.

**Interior ballistics:** The first phase of firing a weapon where the chemical energy stored in the propellant is converted into the kinetic energy of the projectile.

**Internally inconsistent:** A situation in which all of the evidence at a scene is consistent with one version of events.

**Internet service provider (ISP):** A company or other entity that provides Internet service to a given computer.

**Iodine fuming:** Nondestructive method of visualizing latent fingerprints based on the interaction of iodine vapors with lipids in the latent residue; usually used to develop fingerprints on items with high intrinsic value.

**Irreversible work:** In the context of accident investigation, the concept that once some energy is used for a particular process, it cannot be converted back into the kinetic energy it once was.

**Island:** A ridge pattern in fingerprints.

**Isotopes:** Chemical element that exists in alternate forms containing identical numbers of protons and different numbers of neutrons.

**Isotropic:** A material that exhibits only one refractive index (RI) no matter which direction light propagates through the item or what the vibration direction is.

**Jeffreys, Sir Alec:** The first scientist to perform DNA analysis in a forensic case.

**Jurisdiction:** A region or geographical area over which law enforcement or a legal entity can excise authority.

**Label side:** The outer sidewall of a tire.

**Laceration/lacerated:** Injury produced by blunt instruments; characterized by surface abrasion, bridging vessels, and nerves with irregular margins.

**Lacquer:** A type of paint in which the film forms by simple evaporation of the solvent system of the liquid.

**Lands:** Raised areas of rifling.

**Laser-induced fluorescence (LIF):** The detection method used in the capillary electrophoresis method of DNA typing.

**Latent fingerprint:** Fingerprint that cannot be seen under normal ambient lighting. A latent print requires some type of enhancement to clarify ridge details sufficiently to allow comparison and identification.

**Lattes crust test:** A test used in forensic serology to determine the ABO blood type of a stain.

**$LD_{50}$:** The quantity of a substance that kills 50% of a test population.
**Lead snowstorm:** A characteristic pattern of lead deposition that results from high-speed bullet impact with tissue.
**Leukocytes:** White blood cells.
**Lever action:** A type of action used in rifles and shotguns.
**Ligature:** An object such as a belt, rope, or cord that is wrapped around the throat to cause asphyxia.
**Line quality:** Appearance of a written stroke determined by a combination of factors, such as speed, shading, pen position, and skill; ranges from smooth and legible to tremulous and awkward.
**Liquid chromatography–mass spectrometry (LC-MS):** An analytical instrument that combines a liquid chromatograph with a mass spectrometer as the detector; analogous to GC-MS.
**Liquid extraction:** See extraction.
**Livor mortis:** The postmortem reddish discoloration of the body caused by the settling of red blood cells due to gravity.
**Locard's exchange principle:** According to Edmond Locard, when two objects contact each other, materials are transferred from one object to another; the basis for proving contact by analysis of microscopic evidence.
**Loop:** One of three basic fingerprint patterns.
**Low explosive:** Explosives that burn very quickly and must be kept in a confined space to actually explode.
**Low-order explosion:** Explosion characterized by a slower pressure increase relative to high-order explosions.
**Luminol:** A presumptive test for blood that is based on chemical reactions that cause light to be emitted.
**Macroscopic :** Examination of an object with the naked eye.
**Macroscopic crime scene:** The overall or "big picture" crime scene.
**Macroscopic examination:** Visual examination generally performed with the unaided eye; used to identify class characteristics.
**Maggot debridement therapy:** The purposeful use of maggots on living patients to remove dead tissue.
**Maggots:** Fly larvae prior to maturation into adult flies.
**Magna Brush:** Trademark version of magnetic brush that uses magnetic powders to enhance latent fingerprints.
**Maiti test:** A color-based test for nitrites.
**Malingering:** Conscious attempt to feign a physical or mental illness; also called *simulation*.
**Mandible:** Lower jaw.
**Manner of death:** Death occurs in one of four manners: natural, if caused solely by disease; accidental, if it occurs without apparent intent; suicidal, if caused by the deceased; and homicidal, if someone other than the deceased caused it.
**Manual strangulation:** Use of the hands in strangulation.
**Margin of safety:** In a building, purposeful design to support static loads that are several times stronger than what the designer anticipates would typically be needed.
**Marginal abrasion:** A circular or elliptical defect in the skin found when a weapon is fired at a distance.
**Markers of occupational stress:** Visible changes in bone size or shape resulting from overuse of certain muscles and joints.
**Mass casualty event:** An event, natural or caused by humans, in which tens, hundreds, or thousands of people die.
**Mass spectrometry:** Technique based on the detection of vaporized molecules and their ionized (charged) fragments. The detection and display of the spectra are based on the mass-to-charge ratios of the ions. The method is specific for qualitative analysis and useful for quantitative analysis.

**Material fatigue:** Failure caused by repeated application of dynamic loads.
**Maternal lineage:** Genetic component passed through the female lines of a family (mitochondrial DNA).
**McNaughten rules:** Cognitive test of insanity.
**Mechanical trauma:** An injury that results when applied physical force exceeds the tensile strength of the tissue to which the force is applied.
**Mechanism of death:** Biochemical or physiological abnormality produced by the cause of death that is incompatible with life (e.g., ventricular fibrillation, exsanguination).
**Medical examiner:** Government official, always a physician and often a forensic pathologist, charged with investigating sudden and unexpected deaths or deaths from injuries.
**Medulla:** The lengthwise central canal of a hair shaft.
**Melanin:** The pigment that imparts color to hair and skin.
***Mens rea*:** Latin term for "guilty mind," it refers to a person's awareness of the fact that his or her conduct is criminal; the mental element of the crime.
**Mescaline:** A hallucinogen found in cactus buttons.
**Methemoglobin:** An oxidized form of hemoglobin.
**Metric traits:** Anatomical traits that can be measured.
**Michel–Lévy chart:** A chart used in conjunction with polarizing light microscopy to interpret interference colors.
**Microanalysis:** Application of a microscope and microscopical techniques to the observation, collection, and analysis of micro-evidence.
**Microcrystalline tests:** A reaction between the compound of interest and chemical reagent that results in the formation of unique crystals that can be observed with the microscope.
**Micrometer:** A device utilizing a scale calibrated with stage micrometer for measurement of the physical dimensions of material viewed with a microscope.
**Micrometry:** Measurement of dimensions using a micrometer and a microscope.
**Microsatellites:** Short tandem repeat or simple sequence length polymorphisms composed of di-, tri-, tetra-, or pentanucleotide repeats.
**Microscopic crime scene:** Crime scene description based on the type of physical evidence present.
**Microspectrophotometry (MSP):** Generation of transmission, reflection, or absorption spectra from various translucent and opaque samples. The principal types are visible and infrared.
**Mikrosil®:** A substance that has the consistency of putty and that is used to capture impressions.
**Minisatellites:** Simple sequence tandem repeat polymorphism in which the core repeat unit is usually 10 to 50 nucleotides long; variable number of tandem repeats.
**Minutiae:** Ending ridges, bifurcations, and dots in the ridge patterns of fingerprints; the quality and quantity of these features serve as the basis of comparison for latent print identification.
**Misdemeanor:** In criminal cases, the less serious type of offense.
**Misting:** Blood reduced to a fine spray as the result of the application of energy or force.
**Mitochondria:** An energy-producing structure within a cell that contains DNA called mitochondrial DNA. It is not the same as the DNA that is found in the nucleus of the cell.
**Mobile phase:** In a chromatographic system such as thin layer chromatography or gas chromatography, the phase that moves.
**Modification ratio (MR):** The ratio of the smallest circle that contains all the lobes of a noncircular fiber compared to the largest circle that can be drawn in the core of the fiber.
**Modifier:** Material added to paint formulations to alter the characteristics of the dried coating.
**Modus operandi (MO):** Method of operation of a criminal; the principle that a criminal is likely to use the same technique repeatedly and that any analysis and record of the technique used in every serious crime will provide a means of identification in a particular crime.
**Mold cure process:** One of two ways in which retread tires are made. This process utilizes strips of raw rubber that are applied to the used tire carcass. The tire carcass is then placed into a mold where the tread design is molded into the new rubber.

**Momentum:** The state of motion of an object such as a car; calculated as the mass of the object multiplied by its velocity.

**Morphology:** Scientific study of the forms and functions of living organisms; shape and size of an organism in relationship to its function. The adjective form is morphological.

**mtDNA:** DNA found in mitochondria; a circular duplex with a genetic code differing from the universal genetic code.

**Mullis, Kary:** Inventor of the polymerase chain reaction (PCR) technique and Nobel Prize winner.

**Multiserial ladders:** A type of structure found in the medulla of hair.

**Muzzle velocity:** The speed of the bullet when it exits the barrel.

**Myasis:** Infestation of living humans or other vertebrate animals with dipteran larvae (maggots).

**$N_{\parallel}/N_{\perp}$:** The ratio of the refractive index in the parallel direction relative to that in the perpendicular direction.

**Naïve consumer:** A person who does not regularly ingest large amounts of drugs or alcohol.

**NASH:** Acronym for manner of death: natural, accidental, suicidal, homicidal.

**National Institute of Standards and Technology (NIST):** Federal agency responsible for setting, approving, and maintaining measurements and materials standards in the United States (formerly National Bureau of Standards).

**National Integrated Ballistic Information Network (NIBIN):** A database used for acquiring, storing, and analyzing images of bullets and cartridge casings.

**Near-contact wound:** A gunshot wound in which the gun is very close but not touching the skin.

**Ninhydrin:** Common name for triketohydrindene, a chemical that reacts with amino acids to form a recognizable bluish-purple compound called Ruhemann's purple; widely used to visualize latent fingerprints; often requires posttreatment.

**Nitrocellulose:** Gun cotton; main energetic in propellants.

**Nitroglycerine:** An oily material that burns rapidly and is used in propellants.

**Nitroguanidine:** An energetic compound used in triple-base powders.

**Noise treatment:** Arrangement of design elements of various sizes around the circumference of a tire to reduce noise.

**Non-request writing:** Normal writing, done without attention to the writing process.

**Normal hand forgery:** A type of forgery in which the individual does not attempt to copy the victim's signature or writing but rather uses his or her own handwriting style.

**Nucleases:** Enzymes that break down DNA.

**Nucleotides :** Molecule consisting of a base, a pentose sugar, and a phosphoric acid group.

**Numerical aperture (NA):** $NA = N \times \sin(AA/2)$, where AA is the angle of acceptance.

**Objective lens (OBJ):** In a microscope, the lens above the sample.

**Oblique lighting:** Lighting cast across a page of writing at an angle almost parallel with the page.

**Obliteration:** Marking over or through existing writing in an attempt to destroy or remove it.

**Odontology:** The scientific study of dental anatomy and biology of the teeth.

**Opacifiers:** Additives to propellants that prevent radiant energy from penetrating the surface of the powder grains (and initiating burning within the grains).

**Opiates:** A term for the class of narcotic drugs derived from the opium plant, including morphine and codeine. Heroin is produced from morphine.

**Optical bridge:** Device that links two microscopes so the two images can be viewed side by side.

**Optical path difference (OPD):** In polarizing light microscopy, the splitting of rays by a birefringent material causes the two wavefronts to travel in different directions resulting in a difference in path.

**Organized offender:** Exhibits a great deal of thought and planning. The offender maintains control over himself and the victim. Little or no material of evidentiary value is present. Organized crime is carried out in a sophisticated and methodical manner.

**Original equipment manufacturer (OEM) tires:** Original tire installed on a new vehicle; also referred to as OE tires.

**Ossification centers:** Anatomical areas where bone tissue forms from fibrous tissue and cartilage, ultimately becoming a bone element.

**Osteoarthritis:** Inflammatory changes to bony joints, frequently related to overuse and loss of bone density.

**Osteology:** The scientific study of skeletal anatomy and biology.

**Osteometry:** The scientific measurement of the skeleton and of skeletal elements.

**Osteon:** The functional anatomic unit of bone, including bone cells within a mineral matrix.

**Osteoporosis:** A pathological loss of bone density and increase of fracture risk.

**OTC (over the counter):** Medicines that can be purchased without a prescription.

**Overkill:** Administering more trauma than necessary to end a life; overkill indicates personalized anger and suggests the offender knew the victim.

**Ovoid bodies:** Microscopic structures occasionally observed in the cortex of hair.

**Oxidation:** The addition of oxygen to a substance; a reduction in hydrogen in a substance or loss of electrons in a substance.

**Oxyhemoglobin:** The form of hemoglobin when it is bound with oxygen.

**Patching:** Addition of a written stroke to improve a defect in a written line.

**Patent fingerprint:** A fingerprint that is visible without any development.

**Pathology:** The study of disease.

**Pattern matching:** Characterization of a pattern by comparison to standards of known composition.

***p*-Dimethylaminocinnamaldehyde (*p*-DMAC):** Indicator chemical used to detect ammonia when urea is catalyzed by urease; used forensically to detect urine.

**Pen lift:** Break in a written line.

**Pen pressure:** Amount of force applied to a pen or pencil while writing.

**Penetrating wound:** A wound with an entrance but no exit.

**Perforating wound:** A wound with an entrance and exit.

**Perimortem trauma:** Injury that occurs at or about the time of death.

**Perimortem:** An event that occurs at or about the time of death.

**Periodic acid–Schiff (PAS) reagent:** Presumptive test for the presence of vaginal material; glycogenated cells are stained bright magenta.

**Permanent dentition:** The dentition that replaces deciduous teeth and is retained in an adult.

**Personality inventories:** Any of a number of psychological tests that evaluate personality, psychopathology, and mental functioning.

**Petroleum distillates:** Materials derived from crude oil; also called *hydrocarbons* or *petroleum hydrocarbons*.

**Phadebas™ reagent:** Commercial chemical consisting of a dye cross-linked to an insoluble starch. Upon digestion of the starch by amylase, the dye is released into solution. The intensity of color indicates the level of amylase present.

**Pharmacogenomics:** The study of how genetic factors influence toxicology and drug effectiveness.

**Pharmacokinetics:** The study of how a drug or toxin moves through the body; related to ADME.

**Phenolphthalein test (Kastle–Meyer test):** A presumptive test for blood that uses phenolphthalein.

**Phosphoglucomutase (PGM):** A polymorphic isoenzyme system that can be typed.

**Photogrammetry:** The use of digital images or photographs to determine characteristics and dimensions of objects in the images.

**Physical anthropology:** One of the four major subfields of anthropology, focusing on the biological basis of human form, behavior, and variation.

**Physical developer (PD):** A type of fingerprint development that is a photographic-type process based on the deposition of silver onto latent fingerprints.

**Physical match:** A fit between separate pieces of physical evidence in which the fit is similar to puzzle pieces fitting together.

**Picroindigocarmine (PIC):** Dye used to differentially stain spermatozoa for ease of identification. It stains the tail and midpiece green and the anterior head light pink.

**Pigments:** Solid materials that impart color.
**Plaintiff:** The injured party in a civil legal action.
**Plane polarized light:** Light that has passed through a polarizing filter such that it is propagating in a single direction.
**Plasma:** The fluid portion of blood.
**Plastic collision:** Collision between two bodies in which a significant portion of the deformation is permanent.
**Plastic deformation:** Change in shape that results from serious injury, such as when bone is bent beyond its elastic capability to return to the original shape.
**Plastic fingerprint:** Fingerprint impressed into a soft receiving surface; a plastic print has a distinct three-dimensional character.
**Platelets (thrombocytes):** Cells in blood that are involved in clotting.
**Point of convergence:** A three-dimensional point or area from which the blood that produced a bloodstain originated; determined by projecting angles of impact of well-defined bloodstains back to an axis constructed through the point or area of convergence.
**Point of impact (POI):** The location at which a collision took place.
**Polarizer:** In polarizing light microscopy, the filter nearest the sample.
**Polarizing light microscope (PLM):** A microscope equipped with two polarizing elements positioned in the optical path of the microscope.
**Pollen:** A fine powder containing male reproductive cells.
**Polymerase chain reaction (PCR):** A reaction used to make copies of segments of DNA.
**Polymorphism:** The occurrence in a population of two or more genetically determined alternative phenotypes with frequencies greater than could be accounted for by mutation or drift.
**Polypharmacy:** A mixture of drugs.
**Positive identification:** Identification that is medically certain and accepted as such in the court system, generally including identification by an expert using DNA, fingerprints, x-ray matching, or dental record matching.
**Postcranial:** That part of the skeleton that does not include the cranium or skull.
**Postmortem:** An event or process that occurs after the time of death.
**Postmortem drug testing:** The branch of toxicology focused on the analysis of biofluids after death to assist in determining a cause of death.
**Postmortem interval:** The amount of time that has passed after death until the time of discovery of the body.
**Postmortem redistribution:** The redistribution of drugs in the body that occurs after death.
**Powder dusting:** A physical method of visualizing a latent fingerprint.
**Precipitin test:** An antigen/antibody reaction that produces a detectable solid.
**Precure process:** One of two ways in which retread tires are made. This process bonds tread rubber already containing the tread design to the original carcass.
**Precursors:** Substances that can be converted into an abused substance.
**Premeditation:** A collection of deviant thinking into a criminal thought pattern.
**Press test:** A method of performing a presumptive test by pressing a filter paper with reagent against a surface to be tested.
**Presumptive test:** A chemical test which, by production of color or light, indicates the presence of a body fluid of forensic interest (e.g., blood, semen).
**Primary crime scene:** Description of a crime scene based on the location of the original criminal activity; the original scene.
**Primary transfer:** Transfer of trace evidence from its original location to a different location.
**Primer:** (1) A small metal disk containing low explosives used to ignite powder in a firearm. (2) In DNA, small piece of single-stranded DNA used for replication.
**Private laboratory:** A forensic laboratory that is run by a corporation or other non-governmental agency.

**Privileged direction:** The one direction of light propagation allowed to pass through a polarizing filter.

**Profiling:** Investigative analysis of an unsolved crime of violence; may cover victimology, crime reconstruction, significant facts of the autopsy, characteristics and traits of the offender, post-offense behavior, and investigative suggestions.

**Projected bloodstain pattern:** Pattern created when blood is projected or released as the result of force.

**Projective tests:** Psychological test based on the notion that if an individual is shown an ambiguous stimulus and asked to respond, his responses will reveal aspects of his personality, including inner thoughts, wishes, conflicts, and feelings.

**Prosecution:** In a criminal case, the party (government entity) that brings the charges against a defendant or defendants.

**Prosecutorial bias:** The potential tendency of a forensic scientist to make scientific determinations that favor the prosecution.

**Prostate-specific antigen (PSA, p30):** 30-kD protein originating in the prostate gland; used forensically to confirm the presence of azoospermic semen following a positive presumptive test result.

**Proximal end:** Nearest the center or point of attachment. In hair morphology, the root is the proximal end.

**Psycholegal :** Pertaining to legal issues or questions that are addressed by psychologists or other mental health professionals.

**Psychological autopsy:** A postmortem evaluation of behavior and intentions.

**Psychological testing:** Quantitative or quasi-quantitative evaluation of personality, psychopathology, and mental functioning.

**Pubic symphysis:** The part of the pelvis where the two pubic bones join in the front and center of the body. It is connected by cartilage and often used to assess adult age.

**Public laboratory:** A forensic laboratory run by a government agency.

**Pump action:** A type of action used in rifles and shotguns.

**Puparial :** A stage in the lifecycle of an insect that follows the larval stage (e.g., maggot).

**Questionable death:** A death that was not witnessed or that is unexpected.

**Questioned document (QD):** Document whose authenticity or origin is suspect.

**Race:** A socially constructed category that groups people according to certain characteristics, sometimes but not always related to geographic ancestry. It is not accepted as biologically scientific.

**Radial cracks:** Fractures that originate from the impact point and propagate away.

**Radial ply:** Tires in which the plies run straight across the tire, from bead to bead.

**Radiation/radiated heat:** Heat that travels in waves in a straight line from its source.

**Radiographically:** Done using x-rays or radiographs.

**Raman spectroscopy:** A type of vibrational molecular spectroscopy.

**RBCs:** Red blood cells.

**Recoil:** One of three ways in which an automatic or semiautomatic weapon can function.

**Reconstruction evidence:** Evidence of the events leading to, occurring during, and occurring after a crime is committed.

**Refractive index (RI):** Velocity of light ($c$) in a vacuum divided by the velocity of light in the medium of interest ($c_{vac}/c_{med}$).

**Remodeling:** Changes in bone shape as a result of injury or stress to the bone.

**Request writing:** Handwritten standards issued in the presence of an investigator or examiner. See also exemplar.

**Resolving power (RP):** Measure of ability to distinguish fine differences in structure.

**Retouching:** Going back over a written line to correct a defect or improve its appearance; synonymous with *patching*.

**Retread tire:** Tire carcass to which new tread rubber is added to produce a usable tire.

**Revolver:** Handgun that holds cartridges in a rotating cylinder.
**Rheumatoid arthritis:** Pathological joint inflammation that occurs in children and young adults.
**Ricochet:** Bloodstain pattern that results from deflection from one surface to another of large volumes of blood after impact.
**Ridges:** The elevated portions of skin patterns.
**Rifling:** System of spiral lands and grooves cut into the interior of a gun barrel; imparts rotation to fired bullets, improving their accuracy.
**Rigor mortis:** Stiffening of the body after death due to the chemical breakdown of actin–myosin and depletion of glycogen from muscles; a time-dependent change that helps determine time of death.
**Rimfire cartridge:** Firearm cartridge in which the primer compound is placed within the rolled rim of the casing. The firing pin strikes the rim of the cartridge.
**Ruhemann's purple:** A chemical complex formed between ninhydrin and amino acids.
**Rules of evidence:** Generally, the rules used by a court to determine if scientific evidence will be admitted.
**Satellite DNA:** Highly repetitive eukaryotic DNA located primarily around centromeres and found in other places in the genome. The buoyant density of satellite DNA is usually different from that of the other DNA of a cell. The repetitive DNA forms a satellite or off-the-bell-curve fraction in a density gradient because of the base compositions of the repetitive regions.
**Satellite spatter:** Small droplets of blood projected around a drop of blood upon impact with a surface. A wave castoff is considered a form of satellite spatter.
**Saturation stains:** Stains on clothing or other materials in which the blood saturates the material.
**Scanning electron microscope (SEM):** A microscope that allows samples to be viewed at much greater magnification and resolution than is possible by light microscopes. Magnification is possible in the range of 10 to 100,000×.
**Scavengers:** Organisms that feed on dead animals or plants; term is used in forensic taphonomy to refer to animals that deflesh and modify the bone of human remains.
**Sciatic notch:** Curved edge of the adult pelvis on the posterior aspect through which the sciatic nerve passes. The relative size of the sciatic notch is an indicator of sex.
**Scientific certainty:** A very high degree of probability, usually at least 90% but 95% or more when applied to individual identification in a criminal case.
**Scientific method:** The method by which scientists study and advance knowledge of the natural world; it is based on data, observations, and hypotheses.
**Scientific probability:** A high degree of probability, usually above 67%.
**Scrape cutter:** Rifling tool having one or two raised cutting edges that cut the grooves of rifling.
**Second instar :** Second-stage fly larvae resulting from molting of first-star larvae that can penetrate skin by using proteolytic enzymes and the rasping action of their mouthparts.
**Secondary crime scene:** Crime scene location after the original or primary crime scene.
**Secondary electrons (SEs):** Type of electrons emitted during scanning electron microscopy.
**Secondary transfer:** The transfer of trace evidence from a location that was not the original crime scene to another location.
**Secretors:** A person who secretes antigenic substances into body fluids.
**Semiautomatic weapons:** Firearm that fires and reloads itself before firing another shot; a self-loading weapon.
**Semi-jacketed:** A bullet that is covered with another metal such as copper, but not completely.
**Seminal acid phosphatase (SAP):** An enzyme found in abundance in seminal fluid.
**Seminal fluid/semen:** Complex mixture of organic and inorganic substances produced in the post-pubertal male genital tract.
**Serial side:** Inner sidewall of a tire.
**Serology:** The study of blood and other body fluids; in forensic applications, the predecessor of DNA typing.

**Serum:** The fluid portion of the blood minus the clotting factors and formed elements. Contains antibodies and other serum proteins.

**Sexual dimorphism:** In humans, the average difference in shape and size between males and females of the species.

**Sexual psychopath laws:** Legislation intended to regulate the evaluation, treatment, and legal disposition of convicted sex offenders.

**Shading:** Contrast between the written upstroke and downstroke of a line.

**Sharp force trauma:** Injury to soft tissue or bone caused by a sharp-edged or pointed weapon or instrument.

**Shear fracture:** A fracture or failure caused by excessive shearing force.

**Short tandem repeats (STRs):** A simple short sequence of DNA that contains a repeated pattern of A, T, C, and G.

**Sign of elongation:** Microscopic characteristic of anisotropic material. It is positive when the vibration direction of light along the length of the particle has a higher refractive index.

**Signature:** A killer's psychological calling card left at each crime scene across a spectrum of several murders; characteristics that distinguish one murder from all others.

**Silver nitrate:** A chemical method for development of latent fingerprints.

**Simometer:** An instrument developed to measure facial flatness.

**Simulation:** See malingering.

**Single-base powder:** Propellant in which nitrocellulose is the energetic.

**Single-variation method:** A method for determining the refractive index of a material using heated oil.

**Sipes:** Small grooves in a tire design element intended to provide better traction. Sipes vary in depth and are useful for documenting tire wear.

**Sizings:** Material added to paper to change its smoothness, finish, absorbency, and appearance.

**Skeletonized bloodstain:** Bloodstain consisting only of an outer periphery after the central area is removed by wiping when the liquid was partially dried; can also be produced when the center of a completely dried stain flakes away.

**Skid formula:** The formula used by accident investigators to determine how fast a car was traveling before the driver applied his breaks and initiated skidding. It involves the weight and mass of the vehicle, acceleration of gravity, frictional coefficient between the tires and pavement, and the distance skidded.

**Skid mark:** Mark on the surface of a fired bullet made when the edges at the beginning of the rifling scrape the bullet surface or when the nose of the bullet slides on the surface of the forcing cone of a revolver barrel.

**Skidding:** Tires moving across a surface without spinning.

**Slant:** Angle of writing with respect to a baseline.

**Sliding tool mark:** A tool mark made by a sliding motion.

**Slippage:** Mark on the surface of a fired bullet made when the bullet slides along the tops of the lands of the rifling. Slippage marks appear when the rifling is worn or when a subcaliber bullet is fired.

**Slots:** Grooves that run across a tread.

**Small particle reagent (SPR):** A physical method of developing latent fingerprints.

**Smokeless powder:** Propellant composed of nitrocellulose (single-base powders) or nitrocellulose plus nitroglycerin (double-base powders). Smokeless powders contain additives that increase shelf life and enhance performance. They are made in a variety of shapes (rods, perforated rods, spheres, disks, perforated disks, and flakes).

**Snow Print Wax™:** A material used to preserve impressions in snow.

**Sodium rhodizonate test:** A test used for lead and barium.

**Soft point:** Semi-jacketed bullets in which a soft metal plug is inserted into the nose of the bullet.

**Souvenir:** Personal item belonging to the victim of a violent crime that is taken by the offender, such as jewelry, clothing, a photograph, or driver's license. The item serves as a reminder of a pleasurable encounter and may be used for masturbatory fantasies. The offender who takes a souvenir is usually an inadequate person who is likely to keep it for a long time or give it to a significant other. See also trophy.
**Specialist:** A forensic scientist that works only in one area such as a DNA analyst.
**Specific gravity:** The weight of a liquid relative to the weight of the same volume of water.
**Splashed bloodstain pattern:** A stain that results from blood splashing into an existing blood drop or pool.
**Spoliation:** Intentional or negligent destruction or alteration of evidence.
**Stabilizers:** Additive to smokeless powder that reacts with acidic breakdown products of nitrocellulose and nitroglycerin. Diphenylamine and ethyl centralite are common stabilizers.
**Stance:** The track width of a vehicle.
**Starch–iodine test:** A presumptive test used for saliva.
**Static load:** Load or force that does not change; it creates no net motion. Static loads balance each other.
**Stature:** The overall height of an individual.
**Stellate defect:** Star-like tearing of soft tissue seen in contact wounds of the head or sternum.
**Stimulants:** Drug that produces a temporary increase of functional activity or efficiency.
**Stippling:** Disposition of fragments of powder into the skin as the result of a gunshot wound of relatively close range; also called powder tattooing.
**Strap muscles:** Muscles of the neck.
**Striations:** Fine scratch used in the microscopic comparison of bullets and tool marks. Striations are made by minute imperfections inside a gun barrel or on the surface of a tool.
**Subpoena:** A legal order that compels someone to appear and testify in court.
**Subpubic angle:** The angle formed in the front under the joint (pubic symphysis) where the two pubic bones come together. The shape of this angle is used to assess sex in the skeleton.
**Successive colonization:** The process by which a body is colonized by a series of insects spaced out over time.
**Sudden death:** A death that occurs quickly, as in an immediately fatal heart attack.
**Super Glue®:** 2-Methyl and ethyl esters of cyanoacrylate; manufactured as an adhesive and incidentally found to be useful in latent fingerprint development. See also cyanoacrylate fuming.
**Surface tension:** The force that pulls the surface molecules toward the interior of a liquid that decreases the surface area and causes a liquid droplet to resist penetration.
**Suture:** Immovable joint formed by the union of two flat bones in the cranium. This joint tends not to be fused in subadults but gradually may fuse in older adults.
**Swaging:** Rifling method in which a rifling button is forced down a drilled-out barrel blank. The button simultaneously expands the barrel to its final diameter and embosses the lands and grooves on the interior.
**SWGDRUG:** Scientific Working Group for the Analysis of Seized Drugs.
**SWGFAST:** Scientific Working Group on Friction Ridge Analysis, Study, and Technology.
**SWGSTAIN:** Scientific Working Group on Bloodstain Pattern Analysis.
**Takayama test:** A microcrystal test for blood.
**Tandem mass spectrometry:** A detection system with more than one mass spectrometer in series.
**Taphonomic assessment:** The assessment of the condition of the dead body in conjunction with the context in which it was found.
**Taphonomic context:** The environment in which a dead body remains during the time between death and discovery.
**Tattooing:** Marking of the skin that results from a close or contact gunshot wound.
**Teichmann test:** A microcrystal test for blood.

**Telogen stage:** The dormant or resting phase of hair growth. Hair in the telogen phase is shed naturally.

**Tensile fracture:** A failure due to excessive pulling or stretching.

**Terminal stroke:** The ending or last stroke made when writing a letter.

**Terminal velocity:** Maximum speed to which a free-falling drop of blood can accelerate in air; about 25.1 feet per second.

**Tetrahydrocannabinol (THC):** The active ingredient in marijuana.

**Tetramers :** Repeats of four base pairs.

**Tetramethyl benzidine (TMB):** A reagent used in a presumptive test for blood.

**Thematic Apperception Test (TAT):** A test in which a person is shown pictures depicting various everyday situations and is asked to create a story based on the picture.

**Thermolabile:** A substance that breaks down at elevated temperatures.

**Thin layer chromatography (TLC):** The use of a solvent that travels through a porous medium to separate compounds based on their chemical affinity with the solvent and the medium.

**Third instar:** The third stage of maggot growth.

**Three-dimensional impressions:** Impression that has length, width, and depth.

**Tire track width:** Measurement from the center of one wheel to the center of the opposite wheel on the same axle.

**Tire tracks:** The relative dimensions between two or more tires of a vehicle.

**Tire tread impressions:** When a tire contacts a surface, it results in the transfer of the class characteristics of design and size and possibly wear and individual characteristics.

**Total magnification (TM):** The product of the eyepiece and objective lens magnification.

**Total station:** Computerized system for mapping the spatial distribution of scattered remains or evidence at a forensic scene.

**Toxicogenomics:** The study of how genetic factors influence toxicology and drug effectiveness.

**Toxicokinetics:** The study of how a drug or toxin moves through the body; related to ADME.

**Toxicology:** The study of drugs and poisons in the body.

**Trabecular bone:** Less dense, spongy bone inside the denser cortical external framework; also called *cancellous bone*.

**Trace evidence:** Historically, a term used to describe any evidence small in size, such as hairs, fibers, and soil samples, that is analyzed utilizing microscopic techniques.

**Tracing:** Fraudulent signature produced by following the outline of a genuine signature.

**Transfer evidence:** Evidence exchanged or transferred from one location or source to another.

**Transfer pattern:** Contact bloodstain created when a wet, bloody surface contacts a second surface as the result of compression or lateral movement. A recognizable mirror image or a recognizable portion of the original surface may be transferred to the second.

**Transitional ballistics:** The phase in firing a weapon through which the projectile passes as it moves from interior ballistics to exterior ballistics.

**Transverse grooves:** Grooves that run across a tread.

**Trash marks:** Mark left on a finished copy during photocopying; results from imperfections or dirt on the cover glass, cover sheet, drum, or camera lens of a photocopy machine.

**Tread wear indicators:** Rubber bar raised 1/16 inch above the base of the tire grooves; it must appear at least six times on a tire.

**Trier of fact:** The legal entity that will render a decision; typically, the judge or the jury.

**Trigger pull:** Force required to pull the trigger of a firearm and cause it to discharge.

**Triple-base powder:** A propellant in which the energetic ingredients are nitrocellulose, nitroglycerin, and nitroguanidine.

**Trophy:** Personal item belonging to the victim of a violent crime that is taken by the offender, such as jewelry, clothing, a photograph, or driver's license. The item represents and is a reminder of an accomplishment, a victory, in the offender's mind. See also souvenir.

**Turning diameter:** Diameter of the circle that a vehicle makes when its steering wheel is fully turned; the tightest turn a vehicle can make.
**Two-dimensional impressions:** Impression that has length and width, but no significant depth.
**Ultrasonic cavitation:** A technique used in serial number restoration.
**Uniserial ladder:** A type of structure found in the medulla of hair.
**Urea:** The compound found in urine that generates the characteristic odor.
**Vacuoles:** Voids or empty regions within a bloodstain pattern.
**Variable number tandem repeat (VNTR):** Chromosomal locus at which a particular repetitive sequence is present in different numbers in different individuals of a population; a simple sequence tandem repeat polymorphism in which the core repeat unit is usually 250 bases long.
**Vehicle:** The solvent used in paint.
**Vehicle identification number (VIN):** An identification number that describes the vehicle type, the factory where it was made, and the year and week it was built. It is a unique identifier.
**Ventral arc:** A linear arc or ridge of bone that frequently develops on the front of the pubic bone in females, below the pubic symphysis.
**Vibrational spectroscopy:** Spectroscopy involving radiation that causes molecules to vibrate but does not cause bonds to break; infrared and Raman spectroscopy.
**Victimology:** Victim's history (personality characteristics, strengths and weaknesses, occupation, hobbies, lifestyle, and sexual history) that impacts the analysis of a crime; a behavioral study of the victim of a violent crime (usually homicide). The analyst examines reputation, lifestyle, habits, associates, and pastimes to form an opinion about the individual's risk of becoming the victim of a violent crime.
**Video spectral comparison (VSC):** Comparison and differentiation of inks by analyzing the infrared reflecting and luminescing qualities inherent to the ink; most often accomplished using a device made by Foster & Freeman, Ltd.
**Videography:** Recording the scene using continuous video (usually digital).
**Virtual autopsy (virtopsy):** An autopsy using medical imaging techniques and is minimally or not invasive.
**Viscosity:** Thickness of a liquid; resistance to flow.
**Visualization:** Applying a chemical or physical process to visualize a latent fingerprint.
**Vitreous humor:** Ocular fluid (fluid within the eye) that is often utilized as a sample for testing in postmortem toxicology.
**Void areas:** Absence of bloodstain in an otherwise continuous bloodstain pattern. The geometry of the void may suggest an outline of the object that intercepted the blood, such as furniture, a shoe, or a person.
***Voir dire*:** The process by which an expert is questioned to determine whether or not he or she will be accepted as an expert by the court.
**Volume of distribution:** An equation that relates dose of a drug to blood concentration.
**W's:** Acronym for who, what, when, where, and why; the questions associated with a crime.
**Wad/wadding:** Cardboard, fiber, or plastic disk found in shotshells; may be placed between the powder and the shot or over the shot.
**Wadcutter:** A flat bullet used primarily for target practice.
**Walk-through:** Preliminary crime scene survey performed to orient the crime scene investigator to the scene and the physical evidence at the scene.
**Watermark:** Translucent design impressed into paper during manufacture. The design becomes visible when the paper is subjected to transmitted light and helps date a document.
**Wavelength:** The crest-to-crest distance in waves of electromagnetic energy.
**WBC:** White blood cells.
**Wear bars:** Raised areas of tires used to measure wear.

**Wear characteristics:** Characteristics of a pattern or surface that are the result of use.

**Wet chemical procedures:** Procedures that involve solvents, extractions, etc.; not instrumental.

**Wet origin impression:** Footwear impression containing significant moisture from the shoe sole or substrate.

**Wheelbase:** Measurement between the centers of the hubs of the front wheels to the centers of the hubs of the rear wheels; it is very difficult to measure from the tracks made by a vehicle.

**Whorl:** One of three basic fingerprint patterns.

**Working distance (WD):** Distance between the subject and the closest portion of the objective of a microscope when focused. It decreases as the numerical aperture (NA) and resolving power (RP) increase.

**Workplace drug testing:** A branch of toxicology focused on analysis of employee samples.