Introduction to Forensic Science

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Abstract

The chapter “Introduction to Forensic Science” provides an overview of the diverse fields encompassed within forensic science, common types of evidence encountered at crime scenes, the seven principles of forensic science, and significant contributors to the field from around the world. The chapter begins by outlining the multidisciplinary nature of forensic science, including its subdivisions such as forensic chemistry, forensic biology, forensic anthropology, and digital forensics. It emphasizes the importance of integrating various scientific disciplines in the investigation of crimes and the analysis of evidence. Additionally, the chapter discusses common types of evidence encountered in forensic investigations, including fingerprints, DNA, trace evidence, firearms and ballistics, and digital evidence. The seven principles of forensic science, including the Locard’s Exchange Principle and the Principle of Individuality, are presented to highlight the foundational principles guiding forensic investigations. Furthermore, the chapter recognizes major contributors in the field of forensic science from around the world, showcasing their significant contributions and advancements in forensic techniques and methodologies. By providing an overview, this chapter serves as a foundation for understanding the principles and applications of forensic science.

Keywords

Forensic science · Forensic fields · Evidence · Seven principles · Significant contributors

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P. Shrivastava et al. (eds.), *Textbook of Forensic Science*,
https://doi.org/10.1007/978-981-99-1377-0_2

2.1 Introduction

Professor Prasanta Kumar Chattopadhyay defines Forensic science as the application of various scientific methods and techniques for the purposes of justice. As is evident from the meticulously chosen words, the focus is on the use of “scientific methods and techniques” rather than just methods to ensure replicability and reliability or results. Forensic Science is an integral part of the justice administration system, as it provides a way to analyze and interpret evidence in criminal as well as civil investigations. This evidence can be used to identify suspects, support a conviction, or exonerate suspects. The word “forensic” is derived from the Latin word “forensis,” which translates to “forum.” It is defined in several ways by different scientists and authors. “Forensic science is the application of science to the criminal and civil laws that are enforced by police agencies in a criminal justice system” (Saferstein 2015). “Forensic science is a scientific discipline directed to recognition, identification, individualisation and evaluation of physical evidence by the application of methods and principles of natural sciences for the purpose of administration of criminal justice” (Nabar 2002).

Forensic analysis and examination of physical evidence, such as fingerprints and DNA, and nonphysical evidence, such as witness statements and video recordings, is used to draw conclusions about criminal events and help identify suspects. It is also used to support convictions, as forensic analysis is considered more definitive than other forms of analyses. In addition, forensic science has been instrumental in exonerating innocent suspects, as it may conclusively prove that someone is innocent.

Forensic scientists and experts must understand the legal system well, as their testimony is often the deciding factor in a case. As such, they must be familiar with the rules of evidence and procedures for handling, analyzing, and presenting evidence in a court of law. They must be updated with the latest developments in the field and attend relevant conferences, seminars, trainings, and workshops to stay informed.

2.2 The Role of Forensic Science in the Criminal Justice System

Forensic science is a rapidly growing field in many countries across the globe. With the advancement of technology, criminals are also becoming more innovative in devising sophisticated methods to commit crimes, and forensic science is playing an essential role in helping apprehend them. It uses scientific methods, such as DNA analysis, toxicology, biometrics, ballistics, and other technologies, to identify suspects in illegal activities. Forensic science is a vital part of the criminal justice system, as it helps provide evidence to either support or refute a suspect’s and/or a witness’s claims during a trial.

Forensic science encompasses various disciplines and scientific techniques used to analyze physical evidence collected from a crime scene. These evidence include fingerprints, bodily fluids, weapon and tool marks, bloodstains, and fibers. Forensic science is also used to identify victims of a crime or disaster, such as missing persons or mass disasters. Forensic experts can use DNA analysis or other methods to match a victim to a known individual, often a family member. Forensic scientists use various scientific methods to study the evidence and draw conclusions about its significance in a case. They use techniques such as DNA analysis, trace evidence analysis, and ballistic analysis to examine evidence and compare it to other pieces of evidence or known suspects or victims. By doing so, they can establish a link between an individual and a crime.

Forensic scientists also play a vital role in civil cases, such as in personal injury or defamation cases. Forensic experts may be asked to provide expert testimony or analysis to support one side of the case. They may also be asked to testify as expert witnesses in criminal trials. Finally, forensic science can be used to help solve cold cases. This involves reviewing evidence that may have been missed or overlooked during the original investigation. By studying cold cases, investigators can identify new leads or uncover new evidence to help solve the case and assist in the delivery of justice.

2.3 Fields of Forensic Science

Forensic science is essentially used by law enforcement to provide crucial, evidence-based solutions to criminal cases. It is an incredibly complex field of science that requires specialized knowledge and skills to understand and can often be the key to a successful investigation. However, this area is vast and complex, and most people are unaware of the different branches of forensic science and how they can be applied to solve criminal cases. In this section, we discuss the various branches of forensic science, how they are used in criminal investigations, and how understanding them can help further an investigation.

Forensic science is a rapidly growing field of research and practice that can be broken down into many branches. Some are depicted in the figure below (Fig. 2.1), i.e., fingerprints, questioned documents, forensic chemistry, forensic toxicology, forensic biology, forensic serology, forensic anthropology, forensic odontology, forensic physics, forensic ballistics, forensic psychology, forensic biotechnology, digital and cyber forensics, forensic engineering, forensic nanotechnology, forensic entomology, forensic geology, and crime scene investigation. Apart from the ones mentioned in the figure, some other areas include humanitarian forensics, forensic meteorology, forensic metrology, forensic linguistics, forensic stylistics, forensic epidemiology, sports forensics, corporate forensics, forensic accounting, forensic auditing, forensic microscopy, underwater forensics, forensic archeology, drone forensics, cell phone forensics, forensic graphology, wildlife forensics, etc.

There are numerous subdisciplines of forensic science, of which some are briefed in the following sections.

Fig. 2.1 Some of the fields of forensic science

2.3.1 Fingerprints

Fingerprint analysis is one of forensic science's most common and oldest branches. Fingerprint evidence has been used to identify individuals since the nineteenth century. This section is concerned with fingerprint examination and comparison. An expert develops and collects latent fingerprints from crime scenes and compares them to control samples collected from suspects. Various physical, chemical, and instrumental methods are available to aid in developing latent fingerprints. Even if individual identification is impossible, the information obtained can narrow the suspect pool. Apart from fingerprints, palmprints and footprints are also studied as sources of potential information for investigating civil and criminal cases (Saferstein 2015; James and Nordby 2009; Badiye et al. 2019; Yamashita and French 2010; Eckert 1992; Daluz 2015; Bansal et al. 2014; Kapoor et al. 2019a, 2020a; Kapoor and Badiye 2015a,b).

2.3.2 Questioned Documents

This section includes the examination of documents such as sale deeds, personal diaries, suicide notes, threatening letters, property papers, etc. “A questioned document is one that in its entirety or in part is suspect as to authenticity or origin” (James and Nordby 2009). The field of questioned document examination is also one of the oldest subdisciplines of forensic science. The area of questioned document examination is known after the evolving work of Albert S. Osborn, and the principles he established are still used by experts today. A questioned document examiner has to deal with the examination of handwriting, inks, papers, typewritten documents, typewriters, printed matter, printers, security documents, etc. (Saferstein 2015; James and Nordby 2009; Eckert 1992).

2.3.3 Forensic Chemistry

Forensic chemistry is a specialized field within forensic science that focuses on applying chemical analysis techniques to investigate and solve crimes. Forensic chemistry incorporates the analysis of physical evidence such as dyes, pigments, and petroleum products, blood alcohol determination, arson and explosive analysis, gunshot residue (GSR) analysis, etc. The analyses includes both organic and inorganic analyses using different analytical techniques. The various instrumental techniques that forensic chemists widely utilize include gas chromatography coupled with mass spectroscopy (GC-MS), Fourier transform infrared spectroscopy (FTIR), high-performance liquid chromatography (HPLC), atomic absorption spectroscopy (AAS), etc. A forensic chemist is dedicated to examining the composition and nature of substances, determining the source of the evidence, and matching the evidence collected from the crime scene with control samples (Saferstein 2015; James and Nordby 2009; Eckert 1992; Mishra 2021).

2.3.4 Forensic Toxicology

Forensic toxicology is a specialized branch of forensic science that deals with the analysis of biological samples to determine the presence of drugs, alcohol, poisons, and other toxic substances. Forensic toxicology is also used in workplace drug testing, poisoning cases, postmortem testing, investigation of contraband materials, dope testing, etc., and other such toxicological analyses. This field deals with the isolation, identification, and quantification of drugs, poisons, and other toxic substances with the help of modern instrumental techniques. A forensic toxicologist is also asked to analyze different biological fluid samples from victims of accidental or homicidal poisoning cases. Through their analyses and interpretations, forensic toxicologists contribute to the accurate determination of cause of death, the identification of illicit drug use, and the establishment of a comprehensive understanding of the circumstances surrounding various types of cases.

2.3.5 Forensic Biology

Forensic biology is a specialized branch of forensic science that focuses on the analysis of biological evidence to aid in criminal investigations. This field involves the examination of biological evidence such as hair, fibers, blood, diatoms, bones, pollen grains, etc. The prime work that a forensic biologist does is performing DNA profiling on different types of biological evidence such as blood and other body fluids. This also incorporates several other areas such as forensic botany, forensic taphonomy, wildlife forensics, etc. Wildlife forensics deals with the use of scientific principles and techniques in legal concerns entailing wildlife (Saferstein 2015; James and Nordby 2009; Eckert 1992; Gefrides and Welch 2011).

2.3.6 Forensic Anthropology

Forensic anthropology can be defined as application of the theory and methods of anthropology for forensic purposes. This study provides an insight into sex, age, race, and time of death from skeletal remains. A forensic anthropologist examines human remains for three purposes: (1) for identifying the victim or at least providing a biological profile (age, sex, stature, ancestry, anomalies, pathology, individual features); (2) for reconstructing the postmortem period based on the condition of the remains and the recovery context; and (3) for providing data regarding the death event, including evidence of trauma occurring during the perimortem period. Forensic anthropologists can be extremely helpful in mass disasters with significant skeletal remains or in cases of mass burials (James and Nordby 2009; Eckert 1992; Byers 2011; Klepinger 2006).

2.3.7 Forensic Odontology

Forensic odontology refers to the use of the science of dentistry to administer law and justice. Comparing their dental charts and X-rays to the dental evidence from victims can help identify victims of a disaster or homicide. This field also involves the examination of bite marks, lip prints, and rugoscopy on various surfaces, which may assist in cases such as sexual assault, murder, burglary, etc. (James and Nordby 2009; Eckert 1992; Kapoor et al. 2020b; Smitha et al. 2019).

2.3.8 Forensic Serology

Forensic serology is a specialized field within forensic science that focuses on the analysis of body fluids and the identification of blood-related evidence in criminal investigations. This deals with the examination of various bodily fluids such as blood, sperm, saliva, urine, vomit, and so on. Forensic serologists are involved in identifying body fluids using various presumptive and confirmatory tests, which are then sent to DNA analysis. Aside from these common body fluids, some cases may necessitate the examination of other fluids, such as menstrual blood, vaginal secretions, fecal matter, and so on. The evidence is examined following the presumptive and confirmatory tests to determine its origin among other parameters (Saferstein 2015; James and Nordby 2009; Eckert 1992; Gefrides and Welch 2011; Li 2012; Badiye et al. 2020).

2.3.9 Forensic Physics

Forensic physics is a specialized field within forensic science that applies principles of physics to investigate and analyze physical evidence in criminal investigations. This section examines evidence such as paint, glass, soil, and metals. It plays a significant role in investigating minute trace evidence and accident cases in a major crime laboratory. Various instrumental analyses are carried out, including neutron activation analysis, a nondestructive testing method, X-ray diffraction, etc. (James and Nordby 2009; Eckert 1992).

2.3.10 Forensic Ballistics

Ballistics is defined as the study of a projectile in motion. Forensic ballistics is a specialized field within forensic science that focuses on the analysis of firearms, ammunition, and the effects of projectiles in criminal investigations. It involves the examination of firearms, bullets, casings, and other ballistic evidence to determine their connections to crimes, such as shootings and homicides. Forensic ballistics experts study the unique markings left on bullets and cartridge casings by the firearm's barrel, known as "ballistic fingerprints," to match them to specific weapons. Forensic ballistics is classified into three categories: internal ballistics, external ballistics, and terminal or wound ballistics. Internal ballistics studies what happens inside the barrel when a shot is fired. External ballistics studies a projectile after it has left the barrel. Terminal ballistics investigates the projectile after it strikes the target, and wound ballistics investigates the projectile after it strikes a living target. In this section, laboratory examination entails examining bullets, cartridge cases, firearms, and other evidence from the crime scene and comparing it to control samples collected from suspected firearms. This examination is typically performed using a comparison microscope (Saferstein 2015; James and Nordby 2009; Eckert 1992; DiMaio 1999; Karger 2008). By analyzing trajectories, impact patterns, and other characteristics, these experts can reconstruct shooting incidents, identify firearms used, assess gunshot wounds, and provide crucial evidence in court proceedings. Forensic ballistics plays a vital role in connecting weapons to crimes, identifying suspects, and ensuring accurate and unbiased criminal investigations.

2.3.11 Forensic Psychology

Forensic psychology refers to the application of psychological methods, theories, and concepts in legal processes. Forensic psychologists may assist as expert witnesses, criminal profilers, and trial consultants, conduct competence evaluations, and assist litigants and fact finders in other ways. Psychological reports are frequently used to determine what happens to a client in the criminal and civil justice systems, whether through trial, prison terms, remuneration, or prison release plans. Moreover, a significant portion of forensic psychologists' employment pertains to specific populations, often including sexual offenders, violent offenders, drug- and alcohol-related crimes, and child custody work, which they should be aware of (James and Nordby 2009; Eckert 1992; Wrightsman 2001). In addition to identifying the presence of body fluids, forensic serologists often work closely with DNA analysts to extract DNA from these fluids for further genetic analysis.

2.3.12 Forensic Biotechnology

This subdiscipline uses biotechnology-based methods to carry out forensic analysis of evidence. Biotechnology is widely used in DNA forensics, but it has also demonstrated its potential use in forensic medicine and many other fields of forensic science. A forensic biotechnologist can link a suspect to the crime scene or identify an unknown individual by identifying DNA recovered from biological evidence, such as biological fluids, hair, or tissues collected at the crime scene. Using DNA fingerprinting to identify and monitor nonhuman organisms, such as an endangered species, is also one such application of biotechnology in forensics. Forensic biotechnologists use DNA degradation-based methods to determine postmortem intervals in forensic medicine (Shukla 2016; Francoeur 1989; Giuffrida et al. 2018). In addition to DNA analysis, forensic biotechnology also encompasses areas like Forensic Genomics, Microbial Forensics, etc.

2.3.13 Digital and Cyber Forensics

Digital forensics and cyber forensics are closely related disciplines that both involve the investigation and analysis of digital evidence to uncover information related to cybercrimes, computer security incidents, and digital misconduct. While the terms are often used interchangeably, they can sometimes refer to slightly different aspects of the field. While both digital forensics and cyber forensics deal with the analysis of digital evidence, cyber forensics is a more specialized field that centers on investigating cybercrimes and security incidents. Digital forensics encompasses a broader range of cases that involve digital evidence, regardless of whether they are specifically related to cybercrimes. Both disciplines are critical in uncovering the truth behind digital incidents, supporting legal proceedings, and ensuring the integrity of digital evidence in a wide array of contexts. It gathers data from computer systems, mobile phones, networks, wireless communication, storage devices, etc., in a way acceptable in a court of law. Cyber forensic investigation comprises identification, collection or extraction, preservation, interpretation or analysis, and communication as its significant steps. This stream comes into play when any type of cybercrime crops up, such as cyberterrorism, data spoofing, denial of service attacks, hacking, data breaches, phishing, ransomware, malware attacks, cyberstalking, credit card frauds, etc. (Saferstein 2015; James and Nordby 2009; Marcella Jr and Menendez 2002; Shrivastava et al. 2018). Digital forensics focuses on the broader scope of investigating digital devices and electronic systems to gather evidence related to various types of cases, including cybercrimes. This can encompass a wide range of scenarios, such as data breaches, intellectual property theft, fraud, cyberbullying, and more. Digital forensics includes the analysis of digital evidence from computers, smartphones, servers, storage media, and other electronic devices. It involves techniques for data recovery, file analysis, metadata examination, and the reconstruction of events. Digital forensics experts also play a role in traditional investigations where digital evidence is relevant.

2.3.14 Forensic Engineering

Forensic engineering is generally defined as "The application of engineering principles and methodology to answer questions of fact that may have legal ramifications" (Noon 2020). Forensic engineering is a branch of forensic science that focuses on investigating and analyzing engineering failures, accidents, and disasters to determine their causes, contributing factors, and potential legal implications. The key aspects of forensic engineering includes, the investigations of industrial accidents and accidents involving vehicles, recreational vehicles, failure analysis, material analysis, structural analysis, fires, explosions, storm surges, slips and falls, arson, water pipe damage, and more. Thus, forensic engineering has been added to the growing fields of forensic science (Saferstein 2015; James and Nordby 2009; Noon 2020; Cobb 2000). Forensic engineering helps establish liability, allocate responsibility, and inform safety improvements to prevent future accidents. It is used in a variety of contexts, including construction accidents, product liability cases, transportation incidents, and industrial accidents.

2.3.15 Forensic Nanotechnology

Forensic nanotechnology can be defined as utilization of nanotechnology in forensic investigations. Nanotechnology assists forensic science in two ways: one by easily detecting and analyzing nanoscale samples because of which essential evidence that could previously not be collected and analyzed due to the instruments' detection limits can now be explored and two through the use of nanomaterials that have novel properties that allow the collection and preservation of trace prime evidence that could previously not be acquired. Nanotechnology has applications in several forensic science streams, including toxicology, serology, biology, pathology, fingerprinting, questioned document examination, etc. (Chen 2011; Kapoor et al. 2019b, 2021; Lodha et al. 2016; Pandya and Shukla 2018; Shukla et al. 2021).

2.3.16 Forensic Entomology

"Forensic entomology is the branch of forensic science in which information about insects is used to conclude when investigating legal cases relating to both humans and wildlife, although on occasion the term may be expanded to include other arthropods." A forensic entomologist is mainly asked to recognize and identify insects at various phases of their life cycle, collect and preserve insects as evidence, estimate the postmortem interval (PMI) based on factors such as insect evidence, weather conditions, and so on, to provide testimony in a court to demonstrate insect-related evidence discovered at a crime scene. Thus, forensic entomology plays a key role in death investigation (Gennard 2007; Wolff et al. 2001; Goff 2009).

2.3.17 Forensic Geology

Geology is the study of the earth's origin, history, processes, and materials. Forensic geology is a specialized field within forensic science that focuses on using geological principles and techniques to investigate and solve criminal cases and legal investigations. This branch of forensic science involves analyzing various earth materials, such as soil, sediments, minerals, rocks, and other geological features, to provide insights into crime scene reconstruction, victim identification, and suspect profiling. A forensic geologist acts as an expert witness in providing expert testimony about geological activities or circumstances. In addition, sometimes forensic geologists are asked to answer questions about evidence such as the material. Where did the material come from? Is it unique to the crime scene? etc. (Lindemann 2011; Ruffell 2010; Di Maggio et al. 2017).

2.3.18 Forensic Meteorology

Forensic meteorology is "the science of using historic weather records, atmospheric data, eyewitness accounts, and re-enactment simulations to determine the weather conditions at a specific time and location" (Badiye et al. 2016). Nowadays, intensifying climate change has led to an increase in natural calamities and cataclysmic-related phenomena worldwide. Forensic meteorologists work on cases such as murders, car accidents, floods, aviation accidents, pollution, noise abatement, winds, snow, avalanches, lightning storms, and even sonic booms all over the world (Badiye et al. 2016; Scala and Wallace 2009). Forensic meteorology helps provide a scientific understanding of how weather conditions can influence various types of incidents and legal cases.

2.4 Some Common Evidence

Forensic science is critical, as it helps collect and analyze evidence to solve criminal cases. To ensure the best outcome in any given case, it is essential to understand the different types of potential evidence that can be collected during an investigation. Numerous types of evidence can be used in a forensic science case, from physical to digital evidence. The chapters up ahead present the different types of evidence encountered in forensic science investigations to help the readers gain a grasp of how each type of evidence can be used (Fig. 2.2). The advantages and disadvantages of each type of evidence and the importance of properly collecting, preserving, and analyzing the evidence are also discussed. By the end of this book, you will have a greater understanding of the types of evidence that can be used in forensic science and their critical role in solving criminal cases.

Every crime scene is unique and may present unique objects or materials as evidence. However, it is imperative to be aware of the list of potential evidence that

Fig. 2.2 Some evidence that may be encountered at an offence scene

is quite common. This may include fingerprints, palmprints, thumbprints, lip prints, footprints, footwear impressions, bones, dental remains, blood, saliva, semen, epithelial cells, vaginal fluid, urine, fecal matter, mutilated body parts, body organs, firearms, ammunitions, spent cartridges, explosives, glass, tapes, knives, bottles, hammers, swords, rods, soil, fibers, hair, feathers, pug marks, nails, teeth, ligatures, thread, paints, tool marks, photographs, negatives, drugs, toxins, poisonous substances, pollens, diatoms, questioned documents, handwriting samples, security documents, fake currency notes, digital evidence, mobile phones, laptops, computers, and digital storage devices, to name a few.

2.5 The Principles of Forensic Science

Forensic science relies on some basic guiding principles like any other scientific discipline. The seven main principles include the principle of exchange, the principle of individuality, the principle of progressive change, the principle of comparison, the principle of analysis, the principle of circumstantial facts, and the principle of probability (Fig. 2.3).

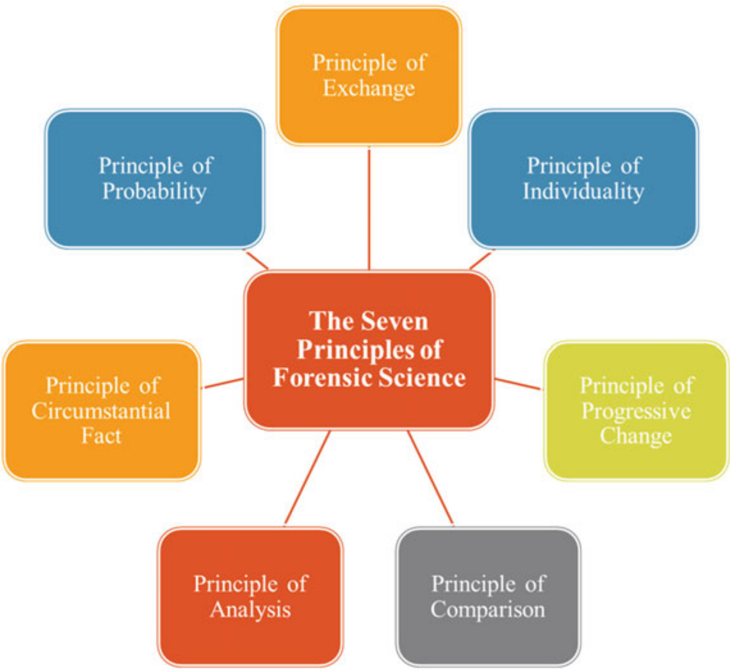

Fig. 2.3 The seven principles of forensic science

2.5.1 The Principle of Exchange

Locard's principle of exchange, often referred to as the principle of transfer, is a fundamental concept in forensic science. Dr. Edmond Locard first proposed it in the early 1900s, and it states that whenever two objects or entities come into contact with each other, there will always be an exchange of material. This material can be anything from fibers to DNA, and it can provide investigators with invaluable evidence for solving crimes. By analyzing the material exchange between two objects, investigators can build a profile of what happened during the crime and who may have been involved. This simple yet powerful idea has helped revolutionize criminal investigations, enabling forensic experts to identify and analyze evidence from crime scenes.

For example, imagine that a suspect touches the door handle of a crime scene; they will leave behind fingerprints, skin cells, sweat, and other materials. By examining this material, investigators can determine who was present at the scene, the probable path followed by that person, and how the crime was committed. This can be used to establish the person's presence at the offence's location. The chance impressions found on the weapon of an offence may also link the suspect to the crime and crime scene. This evidence can then be used to corroborate witness statements and help piece together the crime.

2.5.2 The Principle of Individuality

One of the most critical principles in forensic science is the principle of individuality. This principle acknowledges that every human being is unique and that every criminal act can be linked to a specific individual. It states that "Every object, natural or man-made, has unique quality or characteristics that are not duplicated in any other object." In other words, it may be said that no two things in the world are exactly alike. The principle of individuality is one of the core tenets of forensic science.

The principle of individuality is also vital for evaluating evidence from a crime scene. For example, a fingerprint left at a crime scene can help determine the identity of a suspect or victim (Bansal et al. 2014; Kapoor and Badiye 2015a). In addition, DNA analysis can be used to determine a person's identity (Badiye et al. 2020). For example, if a lip print from a suspect is found at the crime scene, it can be compared to the suspect's lip print sample in order to determine its origin (Badiye and Kapoor 2016; Kapoor and Tiwari 2013). This type of evidence can be used to connect a suspect to a crime scene and eliminate other potential suspects.

By understanding the individual characteristics of the suspect or victim, investigators can more effectively identify the person responsible for the crime. This knowledge can also help eliminate suspects who do not match the individual characteristics identified in the evidence.

2.5.3 The Principle of Progressive Change

The Principle of progressive change states that “Everything changes with the passage of time and nothing remains constant.” This principle holds that all living and nonliving things, including humans, are constantly in a state of change from their birth to their death. The degree of this change can be measured by various factors, including age, environment, and lifestyle. In forensic science, this principle is important for understanding how materials and evidence are affected over time and how they can be used to reconstruct crime scenes and other events.

The first application of the principle of progressive change in forensic science is its use in the analysis of physical evidence. This can include fibers, hair, blood, and other bodily fluids. In this process, examining these materials over time can help identify the age of the material as well as any changes that may have occurred due to environmental factors, such as temperature or humidity.

The principle of progressive change can also be used to analyze trace evidence. Minute changes in the composition and characteristics of these materials can be studied over time to determine the material’s age and any changes caused by environmental factors. This can be especially useful in reconstructing crime scenes and other events.

This principle is also utilized in document examination. Dating of documents is one of the challenging areas in document examination. It uses chronological changes that the components of a document, i.e., ink and paper, undergo with time to estimate the age of records. It encompasses the changes in ink when it is placed on paper, such as drying of ink, color change, solvent evaporation, etc., and changes in paper, such as color change, changes in fibers, etc., with the due course of time and estimates the absolute and relative ages of the document (Kapoor et al. 2021).

2.5.4 The Principle of Comparison

The principle of comparison states that “Only the likes can be compared.” This technique is used to compare fingerprints, handwriting, fabrics, metals, fibers, and other physical evidence that may be found at a crime scene. It compares physical evidence collected from a crime scene to determine whether they match or share a common origin. The comparison of fingerprints can be done with fingerprints and that of footprints can be done with footprints. This principle is often used during forensic investigations to link physical evidence from a crime scene to a suspect or a particular event. For example, if a fingerprint is found on evidence, then the investigator can compare it with a known sample of the suspect’s fingerprints to determine whether the two match.

2.5.5 The Principle of Analysis

The principle of analysis is one of the most important concepts in forensic science. This principle deals with examining and evaluating physical evidence to draw valid conclusions upon which a reliable opinion can be based. This principle states that "The analysis can be no better than the sample analysed."

The principle of analysis is an integral part of forensic investigations. By appropriately and scientifically analyzing the evidence collected during the study, forensic scientists can draw meaningful conclusions that can be used to solve the case. Analysis techniques such as DNA analysis, fingerprint and ballistic comparison, document examination, and toxicology are all important components of the analysis process.

2.5.6 The Principle of Circumstantial Facts

The principle of circumstantial facts states that "Facts do not lie, humans can, and they do." Facts cannot be false. They can neither be entirely missing nor can they lie. The significance of circumstantial facts is thus advantageous for oral testimony. Applying circumstantial facts in forensic science is a complex process, requiring proper evaluation to adequately determine a person's guilt or innocence. Although it is true that circumstantial evidence can be used to make a strong case, it is essential to understand that circumstantial evidence can be easily manipulated to fit different scenarios, making it difficult to draw a definitive conclusion. The suspect or the witnesses may lie intentionally; however, if the evidence pertaining to that particular incident is present at the spot or their analysis reveals otherwise, then the truth would come out. Circumstantial evidence can help corroborate a person's testimony or another type of evidence. This type of evidence can be invaluable in criminal investigations and trials.

2.5.7 The Principle of Probability

The principle of probability states that "All identifications, definite or indefinite, made consciously or unconsciously are based on probability." This has become essential for forensic science. This principle is based on the idea that an event has a certain chance of occurring and that these probabilities can be estimated and used to make decisions. It is used to help determine the likelihood that an individual is responsible for a crime, whether a piece of evidence is reliable, or even to predict the outcome of a trial. In recent years, probability has been used in several forensic applications, including DNA testing, drug analysis, fingerprint examination, and court proceedings.

The use of probability in forensic science is based on the notion that events can be assigned a probability of occurrence. For example, the likelihood that a particular type of DNA will be present in a sample from a crime scene can be estimated by comparing the DNA from the sample to that from a known individual. If the DNA from the sample is found to match the DNA from the known individual, then it is likely that the individual was present at the scene of the crime. Similarly, the probability that a fingerprint will match one from a suspect can be determined by comparing the fingerprints and analyzing the similarity between the two. The use of probability in forensic science has helped improve the accuracy of investigations and the chances of obtaining a conviction.

2.6 Some of the Major Contributors

Forensic science has become an important tool in criminal justice, allowing law enforcement to analyze physical evidence to track criminals and solve cases. It has been used to solve mysteries and crimes since ancient times. Ancient civilizations had their own forms of forensic science, employing techniques such as fingerprinting, handwriting analysis, and analyzing skeletal remains to identify suspects and determine the cause of death. Ancient historians often relied on forensic science to determine the facts about past events, including the identity of those involved and the circumstances surrounding the incidents. In more recent centuries, forensic science has developed into a sophisticated discipline, with scientists utilizing sophisticated tools and techniques to analyze evidence in criminal cases.

In ancient Egypt, forensic science was used to identify the perpetrators of crimes. Fingerprinting was used to help determine whether a document was authentic and to identify an individual who had touched an object. A form of handwriting analysis was also used to identify authors of written documents. In addition, ancient Egyptians utilized skeletal remains to determine the age and sex of murder victims and to help formulate theories about the cause of death.

One of the most interesting uses of forensic science in the ancient world was its application in courtrooms. In ancient Greece, forensic experts would examine the evidence presented at a trial, such as clothing or weapons, to determine the case's truth. Forensic scientists would sometimes even be called to testify as expert witnesses.

The development of more sophisticated laboratory techniques has also allowed forensic scientists to uncover more evidence from a crime scene than ever before. These methods include trace evidence analysis, which looks for microscopic particles of evidence such as soil, blood, and other bodily fluids, and chemical analysis, which looks for the presence of certain chemicals that may indicate a presence at the scene of a crime or a link between a suspect and a crime scene. The following is the list of some of the pioneers who contributed to the growth and development of the field of forensic science.

2.6.1 Mathieu Orfila (1787–1853)

Mathieu Orfila is a pioneer in forensic science and is widely credited with laying the foundations of modern forensic toxicology. He is known as the father of modern toxicology (Saferstein 2015; Nabar 2002; Pyrek 2018). He was a French chemist and toxicologist credited with bringing a scientific approach to the study of toxicology and developing the concept of legal medicine. His work helped revolutionize the criminal justice system by introducing an evidence-based approach to understanding and determining the effects of toxic substances on humans.

Orfila is best known for his seminal work on the effects of poisons and their detection in the human body. He was the first to recognize and document the impact of exposure to toxins that could be used to commit murder and other violent crimes. His book, *Toxicologie Generale*, published in 1814, is one of the earliest texts on the subject and is considered a foundational work in forensic toxicology (Saferstein 2015; Nabar 2002; Pyrek 2018; Wielbo 2000).

In addition to his work on the effects of poisons, Orfila made significant contributions to the study of medical jurisprudence. He was the first to recognize the importance of an autopsy in determining the cause of death and developed the concept of postmortem examination. He also recognized the need for modern approaches to interpreting evidence in criminal cases and developed the idea of using circumstantial evidence in court.

Orfila's work revolutionized the field of forensic science, and his contributions are still used in modern criminal investigations. He was a pioneer in the field, and his work was instrumental in developing modern forensic toxicology and establishing the current criminal justice system.

2.6.2 Alphonse Bertillon (1853–1914)

Alphonse Bertillon was the first to devise a systematic technique for criminal identification based on body measurements, known as the science of anthropometry. This technique employs a series of body measurements to distinguish one individual from another. Bertillon's work has been instrumental in developing forensic anthropology techniques and strategies. He has published several papers on using bone analysis and skeletal reconstruction in criminal investigations. He has also developed techniques for accurately identifying individuals from skeletal remains (Saferstein 2015; Nabar 2002; Pyrek 2018; Wielbo 2000; Hebrard and Daust 2013). His work provided a much-needed foundation for using these techniques in criminal investigations.

2.6.3 Sir Francis Galton (1822–1911)

Francis Galton is the pioneer of modern forensic science. His contribution to forensic fingerprinting has been immeasurable, and he is recognized as the father of the discipline. He is widely credited for introducing fingerprints as a form of identification in the late nineteenth century. His book, *Finger Prints* (1892), was the first to discuss the use of fingerprints in criminal investigations. Galton's research and ideas have been at the heart of fingerprint analysis ever since.

Galton's research into fingerprint analysis involved studying the ridge patterns of fingerprints. He explored the uniqueness of fingerprints and developed the critical techniques used in fingerprint identification and classification. He divided fingerprints into three categories: arch, loop, and whorl. Galton also identified methods for measuring and comparing fingerprints and techniques for collecting and preserving prints.

Galton was also the first to use fingerprints in a court to identify a suspect. He demonstrated that the prints found on the glass were those of a suspect in a murder case. His success, in this case, ushered in a new era of crime-solving and forensics based on fingerprints (Saferstein 2015; Nabar 2002; Yamashita and French 2010; Pyrek 2018; Wielbo 2000; Hebrard and Daust 2013).

2.6.4 Sir Edmond Locard

Sir Edmond Locard was one of the earliest pioneers of forensic science. He is credited for laying the foundation for the development of modern forensic science. He revolutionized how evidence was collected and analyzed, and his work was instrumental in helping law enforcement officials solve crimes. He was a French criminalist and criminologist from the early twentieth century credited with developing the first systematic methods for using physical evidence in criminal investigations. He was the founder of the world's first crime laboratory, which was established in Lyons, France, in 1910.

Locard's exchange principle is the cornerstone of forensic science, and it states that whenever two objects come into contact with each other, a cross-transfer of materials occurs between them. This means that any two items in touch with each other leave behind trace evidence that can be used to identify the source of the material. For example, if a piece of clothing was worn by someone in contact with a murder weapon, then microscopic particles of that weapon could be found on the clothing (Saferstein 2015; Nabar 2002; James and Nordby 2009; Pyrek 2018; Hebrard and Daust 2013).

2.6.5 Dr. Karl Landsteiner (1868–1943)

Dr. Karl Landsteiner was an Austrian physician and immunologist who made significant contributions to the field of medical science, particularly in the area of blood typing and the discovery of blood groups. His groundbreaking research laid the foundation for modern transfusion medicine and earned him the Nobel Prize in Physiology or Medicine in 1930. Landsteiner's contributions to forensic science include developing the classification system to identify different blood types.

Landsteiner's most notable accomplishment was his discovery and classification of human blood groups. In 1900, he identified and categorized blood into four major groups—A, B, AB, and O—based on the presence or absence of specific antigens on the surface of red blood cells. He found that people with type A blood were incompatible with people with type B blood, and vice versa. He also discovered that type O blood could be transfused into any type of blood. This discovery revolutionized blood transfusion practices, ensuring safe and compatible blood transfusions. It was the first step toward establishing a reliable system for identifying blood types in forensic science (Saferstein 2015; Nabar 2002; James and Nordby 2009; Pyrek 2018).

2.6.6 Dr. Leon Lattes (1887–1954)

Forensic serology has been used in solving crime cases since the early twentieth century. In more recent years, the contribution of Leon Lattes to the field has been immeasurable. Leon Lattes was an Italian biologist who developed the first blood typing test. In the year 1915, he instrumented a method for determining the blood group from dried bloodstains. The test was based on the principle of agglutination, which is the clumping together of red blood cells in response to the presence of an antibody. Lattes also developed a method of isolating and identifying the genetic material, or DNA, of blood samples. This technique was also used to identify individuals and to compare bloodstains found at crime scenes. This advancement in forensic serology greatly impacted the criminal justice system, as it allowed for quicker and more accurate case resolution.

2.6.7 Dr. Calvin Goddard (1891–1955)

When it comes to the history of forensic ballistics, Calvin Goddard's name will always be at the top of the list. As one of the earliest pioneers in the field, Goddard was instrumental in establishing the practice of matching bullets and other projectiles to firearms to link suspects to crime scenes. His work on the science of ballistics was the foundation of modern ballistic tests used in criminal investigations.

Goddard's work in forensic ballistics began in 1923 when he was a captain in the US Army Reserve. Goddard and his team successfully matched the bullets from the crime scene to the machine gun and linked the suspects to the crime. This case was one of the earliest examples of using ballistic evidence to solve a crime. However, Goddard's work in forensic ballistics did not stop there. He developed the first handheld comparison microscope, which is still used today to compare bullets with firearm marks. Goddard also wrote several influential books on the topic, including *The Science of Ballistics*. Throughout his career, Goddard advocated for the scientific use of ballistic evidence in criminal investigations.

2.6.8 Albert Osborn (1858–1946)

Albert Osborn is widely regarded as the father of forensic questioned document examination. Osborn's contributions to this field are significant, and his methods remain in use even today. In his book, *Questioned Documents*, Osborn lays the groundwork for developing a scientific approach to document examination.

Osborn was the first to determine that forgery could be identified by analyzing handwriting and other documents. He developed a system for analyzing records that included comparing the handwriting of a questioned document to known handwriting samples, looking for discrepancies in the paper, ink, and writing tools used, and analyzing the text for inconsistencies. Osborn's system was a breakthrough in the field, allowing for a more scientific approach to document analysis.

Osborn also developed a classification system for handwriting types, which is used today. Osborn could identify similarities between documents and make conclusions about their authenticity by categorizing handwriting into various categories, such as looped, angular, and connected.

In addition to his work in the field of forensic questioned document examination, Osborn also wrote many books on the subject, including *The Questioned Document* (1910), *Identification of Handwriting* (1917), and *The Problem of the Questioned Document* (1924). These books have become standard reference works for forensic document examiners (Saferstein 2015; Nabar 2002; Pyrek 2018; Lewis 2014; Osborn 1910).

2.6.9 Hans Gross (1847–1915)

Hans Gross is considered one of the most influential figures in modern forensic criminal investigations. Born in 1847 in the Austrian Empire, Gross was a lawyer and judge who later became the founding figure of criminology, the scientific study of crime and criminal behavior. He was the first to recognize the importance of forensic science in criminal investigations and wrote various influential works on the subject.

One of Gross's most important contributions to the field of criminal investigation was the establishment of the "criminalistics" system, a comprehensive system of collecting, preserving, and analyzing evidence. This system enabled investigators to identify, classify, and analyze relevant evidence, which was then used to build a case against a suspect. It also provided a legal framework for evaluating evidence and its admissibility in court. Gross wrote extensively on the need for strict adherence to the principles of criminalistics, and his work strongly influenced the development of modern forensic science.

2.6.10 Henry Faulds (1843–1930)

Henry Faulds is widely credited with revolutionizing the field of forensic fingerprint analysis. He was a noted British physician and scientist who played a significant role in developing fingerprint identification in the late nineteenth century. Faulds developed the world's first automated fingerprinting system and published the first scientific paper about the use of fingerprints for identification in 1880. He was also one of the first to suggest that fingerprints could be used as a form of personal identification in criminal investigations.

Faulds believed that fingerprints could be used to identify individuals with certainty, as they were unique to everyone. He was also an advocate of using fingerprint analysis to detect criminal activity. He developed a number of techniques for fingerprint analysis, such as dusting for prints and photographically enlarging them. He also developed a method of comparing fingerprints, known as the Henry System, which is still used today (Yamashita and French 2010; Pyrek 2018; Wielbo 2000; Hebrard and Daust 2013).

2.6.11 Sir Edward Richard Henry, Khan Bahadur Azizul Haque, and Rai Bahadur Hem Chandra Bose

Edward Richard Henry, Azizul Haque and Hem Chandra Bose are key figures in the history of the forensic fingerprint science. Assisted by two Indian police officers, sub-inspectors Azizul Haque and Hem Chandra Bose, Henry is credited with developing the fingerprint classification system, which is still used today. This system laid the foundation for modern forensic fingerprint analysis and revolutionized criminal identification worldwide. With their efforts, the world's first fingerprint bureau was set up in Calcutta in 1897 (Sodhi and Kaur 2005). The mathematical formula and the single-digit classification system devised by Azizul Haque and Hem Chandra Bose added a level of sophistication to the fingerprint identification process. These innovations allowed for more efficient organization and retrieval of fingerprint records, making it easier to identify individuals accurately and quickly. The concept of sub-classification further improved the accuracy and speed of identification, facilitating the adoption of fingerprinting as a standard method in law enforcement. Fingerprint analysis remains a cornerstone of criminal investigations and forensic identification, and their efforts have had a lasting impact on law enforcement practices worldwide.

The system was a major breakthrough in the field of forensic fingerprinting. Before this system, law enforcement agencies had little to no way of accurately identifying a person by their fingerprints. The classification system, however, allowed for much more accurate personal identification. In addition, the system allowed for the easy comparison of two fingerprints, which made it easier for investigators to determine whether two sets of prints belonged to the same person. Their work in forensic fingerprinting also helped establish it as an accepted form of identification (Saferstein 2015; Nabar 2002; James and Nordby 2009; Yamashita and French 2010; Sodhi and Kaur 2005).

2.6.12 William Herschel (1833–1917)

William Herschel is widely regarded as one of the pioneers of forensic fingerprinting. He began researching fingermarks in the late nineteenth century, and his work was crucial for the development of fingerprint identification systems. His work laid the foundation for the development of modern forensic fingerprinting techniques.

Herschel's most significant contribution to forensic fingerprinting was discovering the "persistent ridge pattern," which is the basis of modern fingerprinting. He developed a method of fingerprinting based on the idea of measuring the ridge patterns and comparing them to existing prints (Nabar 2002; James and Nordby 2009; Yamashita and French 2010). He noticed that each finger has its own pattern of ridges and furrows, which remain consistent over time.

2.6.13 Paul Kirk (1902–1970)

Paul Kirk was an influential American forensic scientist and biochemist who made significant contributions to the field of forensic science. He played a crucial role in the development and advancement of forensic techniques and methodologies, particularly in the areas of crime scene investigation, bloodstain pattern analysis, and forensic anthropology. He primarily focused on analyzing and identifying trace evidence using microscopic techniques. Kirk developed several techniques to identify the source of trace evidence, such as soil particles, hair, fibers, and glass fragments. He also worked to develop methods to determine the presence of gunshot residue and other residues from firearms (Pyrek 2018; Wielbo 2000; Hebrard and Daust 2013).

2.6.14 Henry C. Lee (1938-Till Present)

Henry Lee is credited as one of the pioneers of forensic science, having made groundbreaking contributions to the discipline. His research and findings have been essential for advancing the study of forensic science, and his work has had a lasting impact on the field. One of Lee's most important contributions was the development of a system of forensic field investigations. He developed a methodology that combined scientific analysis with an understanding of the physical evidence and the crime scene. This system allowed investigators to systematically collect, analyze, and interpret evidence and to conduct an adequate investigation. Lee's approach to forensic field investigation has been widely adopted and is still used today.

2.6.15 Dr. Lalji Singh (1947–2017)

Dr. Lalji Singh was a renowned scientist known as the “Father of DNA Fingerprinting in India.” He was a molecular biologist and was critical in introducing DNA fingerprinting technology to the country’s legal and investigative processes. Dr. Singh was instrumental in setting up the Centre for Cellular and Molecular Biology (CCMB) in Hyderabad, India, and he also played a key role in the establishment of the Centre for DNA Fingerprinting and Diagnostics (CDFD), which became a center of excellence for DNA profiling and forensic applications. His work on DNA fingerprinting had far-reaching implications for criminal investigations, paternity disputes, identification of victims, and missing persons. His contributions were especially significant in high-profile criminal cases, where DNA evidence played a crucial role in solving crimes and providing justice. Dr. Singh’s efforts were not only limited to research but also extended to education and outreach. He was passionate about training forensic experts and promoting the understanding and application of DNA technology in various fields. His work has left a lasting impact on forensic science in India and has paved the way for advancements in DNA analysis techniques.

2.6.16 Sir Alec Jeffreys (1950-Till Present)

Sir Alec Jeffreys is a British geneticist who is widely recognized for his groundbreaking discovery of DNA fingerprinting, a technique that has revolutionized forensic science and has had significant applications in criminal investigations, paternity testing, and more. It provided a highly accurate method for identifying individuals based on their DNA, which was crucial in criminal investigations for linking suspects to crime scenes or victims. The technique has been used to solve countless criminal cases and has also been employed in exonerating innocent individuals who were wrongly convicted. In recognition of his groundbreaking work on DNA fingerprinting, Sir Alec Jeffreys was awarded the Nobel Prize in Chemistry in 1993 “for the discovery of the polymorphic DNA probes, which led to the development of DNA fingerprinting.” He was awarded the prize jointly with Michael Smith, who developed site-directed mutagenesis, a technique used to alter specific genes within organisms. Overall, Sir Alec Jeffreys’ discovery of DNA fingerprinting and his subsequent Nobel Prize have left an indelible mark on forensic science, shaping the way criminal investigations are conducted and enhancing the accuracy and reliability of genetic identification techniques.

2.7 Conclusion

Forensic science has continued to evolve over the centuries, with the development of more advanced tools and techniques for analyzing evidence. Today, forensic experts have access to sophisticated technologies, such as DNA analysis, to help solve crimes. Nonetheless, the basic principles of forensic science have remained unchanged from ancient times, and it continues to be an invaluable tool for crime solving.

Accurate and reliable evidence is essential for criminal cases. Forensic science has come a long way in recent decades and is vital in modern investigations and criminal cases. It is a powerful tool to help solve crimes, and its use has become increasingly prevalent in the legal system. As technology and understanding of the law continue to improve, forensic science will remain a critical tool. The upcoming chapters explain the forensic aspects of different types of evidence in detail.

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