

Forensic Science and Criminal Investigation Procedures

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Abstract- In a way a crime scene is a message in a language that most people don't know. The purpose of forensic science is to read that message, whether it's the blood on a door frame or the pattern of blood on that door frame, or the bits of a hard drive or the pattern of blood on the liver or the trace of poison. The job of forensic science is to read that message, whether it's the blood on a door frame or the pattern of the blood on a door frame, the bits of a hard drive, the pattern of blood on the liver, or the trace of poison. This paper describes a short history of the practical application of forensic science in the crime-solving process since the birth of scientific criminalistics in the late nineteenth century to the present day, including the DNA revolution of the 1980s and the digital and genetic-genealogy tools of the twenty-first century. It reviews the major disciplines of forensic science, the process used for investigation of crime scenes, the chain of custody, the legal requirements for forensic evidence to be presented to a jury, and the research findings about error, cognitive bias and wrongful conviction in what are considered "objective" forensic fields. The book ends with an evaluation of the forensic infrastructure in India and the statutory landscape – past and present – that regulates the application of forensic science in the Indian courts. It is a central argument that the power of forensic science is based on its empirical grounding and procedural rigor, not on the aura of certainty it often emanates from laboratory coats and technical jargon, and that the credibility of criminal investigation rests on respecting that distinction.

Keywords: Forensic Science, Criminal Investigation, Crime Scene, DNA Profiling, Fingerprint Analysis, Chain Of Custody, Forensic Evidence, Admissibility, Wrongful Conviction, Digital Forensics.

I. INTRODUCTION

Before any court asks whether a person is guilty, someone needs to work out what physically happened.

This is the province of forensic science, that is, of the application of scientific methods and techniques to matters of criminal and civil law.¹ The phrase evokes images shaped almost entirely by television, where a single fibre or a dusting of fingerprint can identify a killer in the space of an hour-long episode. In reality, forensic practice is slower, messier, and far more constrained by error rates, laboratory backlogs, and legal standards of admissibility than popular drama would have you believe. Researchers have come to refer to this gap as the CSI effect.^{2 3}

Forensic science is not a single method, but should be seen as a family of applied disciplines each with its own history, strengths and limitations of evidence, but united through their common role in the criminal investigation and adjudication process.⁴ Section 2 gives a conceptual overview of the field. Its history is discussed in section 3. Section 4 reviews the main forensic disciplines separately. In Section 5, we present the procedural skeleton of a crime scene investigation, which includes the collection of evidence and the chain of custody. Section 6 Laboratory standards and accreditation. Then Section 7 considers the legal question of admissibility. Section 8 deals with the uncomfortable but well documented issue of forensic error and cognitive bias. Case studies are provided in Section 9, while emerging technology is discussed in Section 10, the Indian forensic framework is specifically discussed in Section 11 and concluding remarks are made in Section 12.

¹Richard Saferstein, *Criminalistics: An Introduction to Forensic Science*, 12th ed. (Pearson, 2018), p. 3.

²Kelly Rippey Podlas, "The CSI Effect: Exposing the Media Myth," *Fordham Intellectual Property, Media and Entertainment Law Journal* 16, no. 2 (2006): 429.

³Simon A. Cole & Rachel Dioso-Villa, "Investigating the 'CSI Effect' Effect: Media and Litigation Crisis in Criminal Law," *Stanford Law Review* 61, no. 6 (2009): 1335.

⁴National Institute of Justice, "Forensic Science: Overview," nij.ojp.gov (accessed 2026).

II. CONCEPTUAL FRAMEWORK: FORENSIC SCIENCE AND INVESTIGATION PROCEDURE

Forensic science can be usefully divided into two related but distinct functions. First, it's about investigation: locating suspects, piecing together what happened, coming up with leads from physical evidence. The second is evidentiary: delivering analysis that is reliable, well documented enough to be used in court and tested by cross examination.⁵ A technique may be suitable for the first purpose but not for the second. A bloodhound's trail or an informal comparison of tyre tracks might help an investigator to concentrate his efforts without ever being scientifically proven well enough to carry a conviction on its own. Much of the controversy discussed below, especially in regard to pattern-matching disciplines like bite mark and hair comparison, is exactly the result of techniques that moved from the first category into the second without appropriate scientific vetting.^{6 7}

The American Academy of Forensic Sciences breaks the field into sections including criminalistics, pathology and biology, toxicology, digital and multimedia sciences, odontology, anthropology, engineering, questioned documents, and jurisprudence, to name a few.⁸ The paper follows a similar, though condensed, structure, grouping

disciplines according to the physical or digital medium of the evidence they analyse.

The systematic use of physical evidence in solving crime is old enough to have influenced popular fiction long before it became a standard police practice. Arthur Conan Doyle's Sherlock Holmes stories, beginning in 1887, popularised deductive reasoning from physical clues years before most police departments employed anything resembling a forensic laboratory, and later compilations of real cases have traced how fictional expectation and actual practice have influenced one another ever since.^{9 10}

III. HISTORICAL DEVELOPMENT OF FORENSIC SCIENCE

The Austrian jurist Hans Gross is often given credit for coining the term 'criminalistics' and the basic investigative principles in his handbook *System der Kriminalistik* (1893), which included careful and systematic examination of crime scenes, something more commonly taught today.¹¹ A generation later, the French criminologist Edmond Locard came up with what is the discipline's most famous maxim: every contact leaves a trace, meaning that a perpetrator will both bring something to a crime scene and take something away from it.¹² Locard's exchange principle continues to be the theoretical basis for the analysis of all types of trace evidence, from fibres to soil to gunshot residue.¹³

⁵Max M. Houck & Jay A. Siegel, *Fundamentals of Forensic Science*, 3rd ed. (Academic Press, 2015), pp. 1-20.

⁶National Research Council (US) Committee on Identifying the Needs of the Forensic Science Community, *Strengthening Forensic Science in the United States: A Path Forward* (National Academies Press, 2009), p. 1.

⁷President's Council of Advisors on Science and Technology, *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods* (Executive Office of the President, 2016), pp. 46-146.

⁸American Academy of Forensic Sciences, "What is Forensic Science," aafs.org (accessed 2026).

⁹Arthur Conan Doyle, *A Study in Scarlet* (Ward Lock & Co., 1887), often credited with popularising deductive forensic reasoning in fiction.

¹⁰Colin Evans, *The Casebook of Forensic Detection: How Science Solved 100 of the World's Most Baffling Crimes*, 2nd ed. (Berkley Books, 2007).

¹¹Hans Gross, *System der Kriminalistik* (1893), later translated as *Criminal Investigation*, trans. John Adam & J. Collyer Adam (Sweet & Maxwell, 1934).

¹²Edmond Locard, *L'enquête criminelle et les méthodes scientifiques* (Ernest Flammarion, 1920), on the principle later paraphrased as 'every contact leaves a trace.'

¹³Jacques Chisum & Brent E. Turvey, *Crime Reconstruction*, 2nd ed. (Academic Press, 2011), pp. 3-4 (discussing Locard's exchange principle).

Before Locard, the methods of identifying repeat offenders were rather crude. In the 1880s police departments all over Europe adopted Alphonse Bertillon's system of anthropometric measurement, which recorded features such as head length and finger length to create a unique numerical identifier for each individual, before being replaced by fingerprinting.¹⁴ Fingerprint identification itself was developed by the work of several researchers working in roughly parallel: Henry Faulds published early observations on the individuality of skin ridge patterns,¹⁵ Francis Galton established the statistical basis for fingerprint uniqueness and persistence, Edward Henry developed a workable classification system which was subsequently adopted by Scotland Yard,¹⁶ and the Argentine police official Juan Vucetich independently developed a rival classification system with Simon Cole's history of fingerprinting traces the technique's journey from a promising investigative aid to an unquestioned courtroom staple well before its underlying error rates had been rigorously studied.¹⁷ The foundations of modern toxicology were laid by the Spanish-French chemist Mathieu Orfila, whose 1814 treatise on poisons laid out systematic methods for the detection of toxic substances in human tissue. It was not until Karl Landsteiner discovered the ABO blood group system in 1901 that forensic serology really came into its own, providing a biological marker, albeit a fairly crude one, which could be used to exclude or include suspects.¹⁸ In the 1920s firearms identification emerged as a separate discipline, when

Calvin Goddard adapted the comparison microscope for side-by-side examination of bullets and cartridge cases, work that was decisive in several high-profile American prosecutions of the era.¹⁹

The most important event in the modern history of the field happened in 1985 when the British geneticist, Alec Jeffreys, discovered that some parts of human DNA differ enough between individuals to be useful as a unique identifying mark. He called this technique genetic fingerprinting.²⁰ The method was first used operationally in the investigation of the murders of two English schoolgirls, a case that led to the conviction of the real killer and the exoneration of a false confessor, foreshadowing the dual power of DNA evidence to convict and to clear.²¹ Short tandem repeat analysis, now the gold standard DNA typing method worldwide, and large scale databases such as the American Combined DNA Index System, have since changed both investigation and post-conviction review.^{22 23}

IV. MAJOR BRANCHES OF FORENSIC SCIENCE

4.1 Forensic Biology and DNA Profiling

Still the forensic discipline with the most solid empirical base is DNA profiling, because the basic biological tenet, the close to uniqueness of an individual genome apart from identical twins, combined with well-characterized statistical models for random-match probability, has been extensively validated. DNA evidence, however, is not infallible.

¹⁴Alphonse Bertillon, Identification anthropométrique: instructions signalétiques (Imprimerie administrative, 1893).

¹⁵Henry Faulds, "On the Skin-Furrows of the Hand," Nature 22 (1880): 605.

¹⁶Edward R. Henry, Classification and Uses of Finger Prints (George Routledge & Sons, 1900).

¹⁷Simon A. Cole, Suspect Identities: A History of Fingerprinting and Criminal Identification (Harvard University Press, 2001), pp. 32-60.

¹⁸Karl Landsteiner, "Über Agglutinationserscheinungen normalen menschlichen Blutes," Wiener Klinische Wochenschrift 14 (1901): 1132.

¹⁹Calvin Goddard, "Forensic Ballistics," Army Ordnance 6 (1925): 108, on the development of the comparison microscope for firearms identification.

²⁰Alec J. Jeffreys, Victoria Wilson & Swee Lay Thein, "Individual-Specific 'Fingerprints' of Human DNA," Nature 316 (1985): 76.

²¹Joseph Wambaugh, The Blooding (William Morrow, 1989), recounting the Colin Pitchfork case, the first criminal investigation resolved through DNA profiling.

²²John M. Butler, Advanced Topics in Forensic DNA Typing: Methodology (Academic Press, 2012), pp. 5-10, on short tandem repeat (STR) analysis.

²³Federal Bureau of Investigation, "Combined DNA Index System (CODIS)," [fbi.gov](https://www.fbi.gov) (accessed 2026).

Mixed samples from multiple donors, low-quantity or degraded samples, and the risk of laboratory contamination all introduce layers of interpretive complexity that have created their own share of wrongful convictions and courtroom controversy.^{24 25 26} The reach of DNA databases has expanded dramatically through international cooperation: cross-border matching systems such as Interpol's DNA Gateway allow member states to search profiles against records held in other national laboratories, extending the investigative reach of DNA evidence far beyond the confines of a single jurisdiction. National laboratories, such as the FBI Laboratory in the United States, are casework laboratories and standard setters. Validation studies and protocols, often in modified form, are used by forensic laboratories elsewhere.²⁷

4.2 Fingerprint and Pattern Evidence

The methodology of latent fingerprint examination is called ACE-V: Analysis, Comparison, Evaluation and Verification. An examiner analyses the quality of a latent print, compares it to a known exemplar, reaches a conclusion and that conclusion is independently verified by a second examiner. The technique has a long history of investigative success, but the 2009 National Academy of Sciences report and subsequent work by Simon Cole and others demonstrated that fingerprint examiners' claims of absolute, error-free certainty were not empirically supported, and that proficiency testing revealed a non-trivial error rate under realistic conditions.²⁸ The most cited example of that risk is the wrongful arrest of American lawyer Brandon Mayfield, who was identified by FBI examiners as a suspect in the 2004 Madrid train

bombings based on a partial latent print, and to this day.²⁹

4.3 Forensic Ballistics and Toolmark Analysis

Firearm and toolmark examination compares microscopic striations on bullets, cartridge cases or tool-marked surfaces to determine if they were produced by a specific weapon or instrument, based on the principle that manufacturing and wear processes make each tool's surface unique.³⁰ Databases such as the American National Integrated Ballistic Information Network allow investigators to search recovered ballistic evidence against records from unsolved shootings.³¹ Databases like the American National Integrated Ballistic Information Network allow investigators to compare recovered ballistic evidence to records from unsolved shootings. The 2016 review of the PCAST report concluded that the foundational validity of the discipline was only partially established, noting that examiner conclusions of a definitive match had not been subjected to the same level of rigorous black-box testing as DNA analysis.

4.4 Forensic Toxicology and Pathology

A key role of forensic toxicology is to detect drugs, alcohol, or poisons in bodily fluids and tissues, both when determining cause of death and in the prosecution of offences such as driving while intoxicated. The closely related but separate field of forensic pathology is the medical examination of a body, usually by autopsy, which is used to establish the cause and manner of death, for which Michael Baden has written an account of the practical

²⁴Erin Murphy, *Inside the Cell: The Dark Side of Forensic DNA* (Nation Books, 2015), on the limits and risks of DNA evidence.

²⁵Peter Gill, *Misleading DNA Evidence: Reasons for Miscarriages of Justice* (Academic Press, 2014).

²⁶William C. Thompson, "Painting the Target Around the Matching Profile: The Texas Sharpshooter Fallacy in Forensic DNA Interpretation," *Law, Probability and Risk* 8, no. 3 (2009): 257.

²⁷Federal Bureau of Investigation Laboratory, "About the FBI Laboratory," fbi.gov (accessed 2026).

²⁸Simon A. Cole, "More than Zero: Accounting for Error in Latent Fingerprint Identification," *Journal of Criminal Law and Criminology* 95, no. 3 (2005): 985.

²⁹Office of the Inspector General, US Department of Justice, *A Review of the FBI's Handling of the Brandon Mayfield Case* (2006).

³⁰Association of Firearm and Tool Mark Examiners, "Theory of Identification as it Relates to Toolmarks," *AFTE Journal* 30, no. 1 (1998): 86.

³¹National Integrated Ballistic Information Network, Bureau of Alcohol, Tobacco, Firearms and Explosives, atf.gov (accessed 2026).

procedures in American medico-legal death investigation.³²

4.5 Trace Evidence Analysis

Operationalized as Locard's exchange principle, trace evidence encompasses such material as fibres, glass, paint chips, soil, and gunshot residue that comes into contact between a person, an object and a crime scene. Trace evidence analysis is usually used to support or disprove a hypothesis about the presence of a suspect at a scene, since such evidence is rarely unique like DNA and fingerprint evidence; it is rarely used for identification alone.

4.6 Forensic Anthropology, Odontology, and Entomology

Forensic anthropology is the application of skeletal biology to the identification of human remains, inferring characteristics such as age, sex and stature from bone structure. It has been pioneered in the United States through research facilities such as William Bass's outdoor decomposition research site, informally known as the body farm.³³ Forensic entomology uses the predictable order of insect colonisation of a decomposing body to estimate the postmortem interval; a technique described in detail by entomologist Lee Goff.³⁴ Forensic odontology, the use of dental records and bite marks, has had a more troubled recent history. While the comparison of dental records for identification of victims is well supported, in multiple documented cases the comparison of bite marks on skin has been shown to lack the scientific reliability it once claimed,

contributing to a number of now-overturned convictions.^{35 36 37}

4.7 Questioned Document Examination

Questioned document examiners use handwriting, ink, paper, and printing techniques to ascertain the authorship or authenticity of a questioned document, a field which began to be discussed in the early 20th century by Albert Osborn and was crystallized by Ordway Hilton.^{38 39} Like other pattern comparison subjects, handwriting has been subject to questioning with regard to the empirical basis of the level of confidence the examiner can have, although for handwriting, as for document dating, there is some more direct measurement of the chemistry on which to base that confidence.

4.8 Digital and Cyber Forensics

The newest major area of digital forensics is the extraction and analysis of computer, mobile device and network data in a way designed to ensure evidentiary integrity, a process described in great detail in the standard textbook on the subject by Eoghan Casey.⁴⁰ Together with the rise of cybercrime, the discipline has expanded rapidly and is now regularly involving itself in issues of encryption, cloud storage, and cross-border access to data that were never part of the realm of traditional forensic disciplines.

4.9 Fire and Explosion Investigation

Arson and explosion investigation is a forensic technique that blends chemistry, engineering and

³²Michael M. Baden & Marion Roach, *Dead Reckoning: The New Science of Catching Killers* (Simon & Schuster, 2001), on forensic pathology and autopsy practice.

³³William M. Bass & Jon Jefferson, *Death's Acre: Inside the Legendary Forensic Lab the Body Farm* (G.P. Putnam's Sons, 2003).

³⁴M. Lee Goff, *A Fly for the Prosecution: How Insect Evidence Helps Solve Crimes* (Harvard University Press, 2000).

³⁵American Board of Forensic Odontology, "Bitemark Analysis: Standards and Guidelines" (2018).

³⁶Radley Balko & Tucker Carrington, *The Cadaver King and the Country Dentist: A True Story of*

Injustice in the American South (PublicAffairs, 2018), on the misuse of bite mark evidence.

³⁷Innocence Project, "Keith Allen Harward," innocenceproject.org (accessed 2026), on wrongful conviction based on bite mark comparison evidence.

³⁸Albert S. Osborn, *Questioned Documents*, 2nd ed. (Boyd Printing, 1929).

³⁹Ordway Hilton, *Scientific Examination of Questioned Documents*, rev. ed. (CRC Press, 1993).

⁴⁰Eoghan Casey, *Digital Evidence and Computer Crime: Forensic Science, Computers, and the Internet*, 3rd ed. (Academic Press, 2011).

crime scene reconstruction to answer the questions of what caused and how a fire developed, and is unique among the forensic sciences in that it is subject to a widely adopted technical guide and is updated regularly to reflect developments in fire science, NFPA 921: Recommended Practice on the Investigation of Fire, Explosion, and Arson, produced by the National Fire Protection Association.⁴¹ In a field where much of the work was once based on folk indicators that were later to be proven unreliable, such as the classic burn-pattern interpretation, conforming to a tested, published protocol has become the focus of defensible fire scene testimony as demonstrated by John Lentini's protocols for documenting a fire scene.⁴²

V. CRIME SCENE INVESTIGATION PROCEDURE

5.1 Securing and Documenting the Scene

Everything that follows from the initial crime scene response is dependent upon the integrity of the initial scene. Standard operating procedures include perimeter security, access control, and contamination control, then careful documentation via photography, video and detailed sketching prior to a move. Investigators usually begin searching systematically, by a search pattern, which in most cases is a grid, spiral or zone search depending on the size and terrain of the scene to be searched, in order to not miss any area.

5.2 Evidence Collection and Preservation

Physical evidence must be collected using methods suitable to the type of evidence, namely, biological evidence needs to be collected and dried in a way that does not degrade the evidence; trace evidence needs to be collected in a manner that does not result in cross-contamination of the evidence; and digital evidence

needs to be collected by forensically sound means that preserve the evidence without alteration. Packaging and crime scene storage may destroy the evidentiary value of a crime scene result, even if the eventual lab work is complex, hence the importance of crime scene procedure, which is often the biggest factor when it comes to the future usefulness of the evidence. In cases that require evidence to be gathered directly from a living victim, such as sexual assaults, specialised forensic nursing protocols have been developed to ensure that the examination and collection of evidence are conducted to meet the clinical and evidentiary requirements of the examination, while also meeting the psychological needs of a person suffering from trauma.⁴³

5.3 Chain of Custody

A chain of custody is the chronological documentation of the collection, handling, transportation and analysis of a specific item of evidence from its time of collection until its presentation in court. A missing link in that chain affords the defense the opportunity to challenge the evidence's authenticity or integrity, and in the United States and India, evidence has been suppressed or discredited where the chain of custody is not sufficiently established.⁴⁴ This is a concern of Indian criminal procedure, which is given statutory expression by the provisions relating to the reports of government scientific experts, to the effect that the expert's report shall be read in evidence without his oral testimony under certain conditions.^{45 46}

VI. LABORATORY ANALYSIS, QUALITY ASSURANCE, AND STANDARDS

Unlike the research laboratory, the forensic laboratory must also be subjected to a limitation on its output, because the output of the forensic laboratory may be

⁴¹National Fire Protection Association, NFPA 921: Guide for Fire and Explosion Investigations (2021 ed.).

⁴²John J. Lentini, *Scientific Protocols for Fire Investigation*, 3rd ed. (CRC Press, 2018).

⁴³Kelly M. Pyrek, *Forensic Nursing* (CRC Press, 2006), on trauma-informed forensic evidence collection from victims.

⁴⁴Sandra Guerra Thompson, *Cops in Lab Coats: Curbing Wrongful Convictions through Independent Forensic Laboratories* (Carolina Academic Press, 2015).

⁴⁵Code of Criminal Procedure, 1973, § 293 (reports of certain government scientific experts).

⁴⁶Bharatiya Nagarik Suraksha Sanhita, 2023, § 329 (corresponding provision on reports of government scientific experts).

the basis for a person's liberty, and this has led to the development of formal accreditation and proficiency testing regimes. The 2009 NASEM report noted that there were inconsistencies in how methodology, validation studies and quality control procedures in the thousands of forensic laboratories currently in the United States are applied to standards published in the field. The National Accreditation Board for Testing and Calibration Laboratories does a similar role in India, accrediting forensic science labs to international standards and the network of Central and State Forensic Science Labs are providing the backbone for forensic science cases in the country.^{47 48 49}

In forensic science, quality assurance is usually multi-layered, consisting of SOP's for every analytical technique, blind proficiency testing (BPT) of individual examiners, technical and administrative review prior to release of results, and periodic external audits.⁵⁰ The failure of any of these layers has been blamed in particular cases of documented forensic failure ranging from the mishandling of DNA samples to fabricated toxicology results, making it clear that the scientific validity of a technique does not imply that scientists in any given lab are reliable. In the United Kingdom, the government-owned Forensic Science Service, a once highly respected government forensic provider, was closed in 2012 following a shift to a competitive private-provider market, partly due to warnings about the capacity and quality-control pressures on the country's forensic supply chain; the United Kingdom has since established an independent Forensic Science Regulator with statutory codes of practice.^{51 52}

⁴⁷Directorate of Forensic Science Services, Ministry of Home Affairs, Government of India, dfss.gov.in (accessed 2026).

⁴⁸Central Forensic Science Laboratory, Government of India, cfsi.gov.in (accessed 2026).

⁴⁹National Accreditation Board for Testing and Calibration Laboratories, "Forensic Science Laboratories Accreditation," nabl-india.org (accessed 2026).

⁵⁰Kelly M. Pyrek, *Forensic Science Under Siege: The Challenges of Forensic Laboratories and the Medico-Legal Death Investigation System* (Academic Press, 2007).

VII. ADMISSIBILITY OF FORENSIC EVIDENCE IN COURT

7.1 *The Frye and Daubert Standards*

The standard in *Frye v. United States* was generally adopted by American courts throughout the twentieth century, and expert testimony was accepted only when the scientific method being used had reached "general acceptance" within its specific scientific community. In *Daubert v. Merrell Dow Pharmaceuticals*, the Supreme Court's decision in 1993 changed that standard in federal court to a more rigorous, "judge-gatekeeping" standard that would require trial judges to evaluate such factors as whether a technique has been tested, peer-reviewed, has a known or potential error rate, and has been generally accepted. The judge's "gatekeeping" function was expanded and clarified in the subsequent cases of *General Electric Co. v. Joiner* and *Kumho Tire Co. v. Carmichael*, and the standard now appears in Federal Rule of Evidence 702.^{53 54 55} In 2016, the PCAST report further reviewed the disciplines of forensic comparisons on the basis of this framework, and found that several, including bite mark, and some types of firearms comparison, had not yet reached the level of established foundational validity required by *Daubert*.

7.2 *The Indian Evidentiary Framework*

In India, the question of expert evidence is primarily dealt with under Section 45 of the Indian Evidence Act, 1872, which is now incorporated into *Bharatiya Sakshya Adhiniyam*, 2023, as Section 39, where it is stated that the opinion of a person specially skilled in a science or an art to which the case relates or in a

⁵¹Forensic Science Regulator (United Kingdom), "Codes of Practice and Conduct for Forensic Science Providers," gov.uk (accessed 2026).

⁵²House of Commons Science and Technology Committee (UK), *Forensic Science Strategy* (2016), documenting the closure of the Forensic Science Service in 2012.

⁵³*General Electric Co. v. Joiner*, 522 U.S. 136 (1997).

⁵⁴*Kumho Tire Co. v. Carmichael*, 526 U.S. 137 (1999).

⁵⁵Federal Rules of Evidence, Rule 702 (testimony by expert witnesses).

forensic science is admissible as evidence.^{56 57} While in the American Daubert regime, the scientific validity of a particular forensic technique rarely is the subject of a judicial gatekeeping doctrine before the technique is admitted, the Indian law has developed a less detailed judicial gatekeeping doctrine in that regard. Indian law is based on cross-examination and judicial evaluation of the qualifications and reasoning of the expert at trial. The Supreme Court of India in *Selvi v State of Karnataka*, directly addressed the admissibility of scientifically obtained but constitutionally sensitive evidence like narco-analysis, polygraph examination, and brain electrical activation profiling, which should not be adduced without the subject's informed consent, on account of the implications it has to the constitutional protection of personal liberty and against self-incrimination.^{58 59} In India, the admissibility of electronic and digital evidence, which has become a major type of forensic evidence, is now regulated on the basis of the provisions of electronic records under the Information Technology Act and its successor *Bharatiya Sakshya Adhiniyam*.^{60 61}

VIII. FORENSIC ERROR, COGNITIVE BIAS, AND WRONGFUL CONVICTION

The 2009 report by the National Academy of Sciences ("FALCO") was a watershed moment for the public discussion of forensic science, as it was the first major scientific body to make a clear statement that, apart from nuclear DNA analysis, there was no forensic method that had been proven to reliably and consistently establish a link between evidence and a particular person or source. That conclusion was reiterated in the 2016 update to the PCAST report,

which was released for several of those pattern-comparison disciplines, causing a great deal of discussion in the forensic and legal communities.

It's not just that there are not validation studies, as is the case with many other cognitive scientists, but that there is cognitive bias in forensic examination itself, as research by cognitive scientist Itiel Dror shows. In one series of experiments, Dror showed that the opinion of fingerprint examiners could be influenced by irrelevant information that would simply tip them off that a certain suspect had already confessed to the crime, even when it was the same print they had earlier, and correctly, rejected.^{62 63} The body of research has led to a call for context blind examination procedures where the analyst is protected from irrelevant information in the case that is irrelevant to the examination task at hand.

The effects of invalidated or arrogant forensic evidence are not hypothetical. In the past, the Federal Bureau of Investigation itself has found that its examiners had been making their conclusions too strong in the overwhelming majority of cases reviewed for which they had already given their opinions—several of which have already led to execution or long prison terms. Bite mark comparison evidence has been used in many wrongful convictions since then which have been overturned with DNA exoneration, such as the case of Keith Harward, who spent over 30 years in prison before being exonerated. The FBI's own programme to identify the composition of bullets by trace amounts of chemical analysis was terminated because the National Research Council determined

⁵⁶Indian Evidence Act, 1872, § 45 (opinions of experts).

⁵⁷*Bharatiya Sakshya Adhiniyam*, 2023, § 39 (corresponding provision on expert opinion).

⁵⁸*Selvi v. State of Karnataka*, (2010) 7 SCC 263 (Supreme Court of India), on narco-analysis, polygraph, and brain electrical activation profiling.

⁵⁹*State of Bombay v. Kathi Kalu Oghad*, AIR 1961 SC 1808, on the constitutional protection against self-incrimination and the taking of physical specimens.

⁶⁰Information Technology Act, 2000 (India), § 65B (admissibility of electronic records), as amended.

⁶¹*Bharatiya Sakshya Adhiniyam*, 2023, § 63 (admissibility of electronic and digital records).

⁶²Itiel E. Dror, "Cognitive Neuroscience in Forensic Science: Understanding and Utilizing the Human Element," *Philosophical Transactions of the Royal Society B* 370 (2015): 20140255.

⁶³Itiel E. Dror & David Charlton, "Why Experts Make Errors," *Journal of Forensic Identification* 56, no. 4 (2006): 600.

that the statistical underpinnings were not supported.⁶⁴ Misapplied or overstated forensic testimony is one of the common themes that unearths itself time and again in broader surveys of misconduct in exoneration cases collected by innocence organisations, or by academic researchers who study exonerations.^{65 66}

IX. ILLUSTRATIVE CASE STUDIES

9.1 *The Colin Pitchfork Case: DNA's Dual Power*

The key strengths of DNA profiling are both evident in the first case solved using the technique: the same DNA profile that convicted the real killer of two English school girls in 1983 and 1986 resulted in the acquittal of an initial suspect who had been led to confess by police questioning, a result that would have been missed in any purely confession-based investigative process.

9.2 *The Golden State Killer and Forensic Genetic Genealogy*

Through the same method, investigators in 2018 have been able to upload DNA from a crime scene to a public genetic genealogy database and trace back to distant familial matches, a method which, since then, has been applied in hundreds of other cold cases throughout the country and has raised much debate about consumer genetic databases and privacy.^{67 68}

9.3 *Crime Scene Handling in the Aarushi Talwar Investigation*

The 2008 investigation into the double homicide of a teen and a domestic worker in Noida, India, was an extremely publicized example of the negative impact of inadequate crime scene management practices and has sparked significant public debate regarding the reliability of the investigation due to contamination of the crime site by investigators, late forensic sampling of the crime scenes and mis-handling of physical evidence.^{69 70}

X. EMERGING TECHNOLOGY IN FORENSIC SCIENCE

Rapid DNA technology, which can produce a DNA profile from a buccal swab sample in less than two hours - with a portable device outside of a conventional crime lab environment - has progressed from research prototype to use at some booking stations, formalised in the U.S. by the Rapid DNA Act of 2017.^{71 72} Forensic genetic genealogy, in the example of the Golden State Killer mentioned above, is an application of DNA evidence that extends its investigative power beyond direct database matches, but with legal experts warning of the need for greater transparency and protections regarding consent, privacy and current regulatory frameworks. Legal historians David Kaye and Jay Aronson have separately chronicled the importance of DNA evidence's rapid legal acceptance, as compared to the

⁶⁴Committee on Scientific Assessment of Bullet Lead Elemental Composition Comparison, National Research Council, Forensic Analysis: Weighing Bullet Lead Evidence (National Academies Press, 2004), documenting the FBI's discontinuation of comparative bullet lead analysis.

⁶⁵Innocence Project, "Overturning Wrongful Convictions Involving Misapplied Forensics," innocenceproject.org (accessed 2026).

⁶⁶Sarah L. Cooper, ed., Controversies in Innocence Cases in America (Routledge, 2014).

⁶⁷CeCe Moore & Colleen Fitzpatrick, "Forensic Genetic Genealogy: A New Investigative Tool," Forensic Magazine, 2019, on the identification of the Golden State Killer.

⁶⁸Paige St. John, "How Investigators Used DNA and Genealogy to Track Down the Golden State Killer Suspect," Los Angeles Times, April 27, 2018.

⁶⁹Central Bureau of Investigation, Government of India, "CBI Investigation Report on the Aarushi Talwar-Hemraj Double Murder Case" (2010), on disputed forensic evidence handling and crime scene contamination.

⁷⁰Aviroom Sen, Aarushi (Penguin Books India, 2015), a journalistic account examining lapses in the crime scene investigation.

⁷¹Sue M. Ballou et al., Rapid DNA Analysis for Booking Stations and Beyond, National Institute of Justice Report (2017).

⁷²Rapid DNA Act of 2017, Pub. L. No. 115-50 (United States).

decades of still-unresolved skepticism that older pattern-matching disciplines have faced, demonstrating the advantages and dangers of courts eagerly accepting a forensic technique before it is mature enough to understand all of its possible practical failure modes.^{73 74}

The size and encryption of today's data are changing the nature of digital forensics, which requires case law and best practices that are constantly evolving and new

tools for extracting data from mobile devices, acquiring data from clouds and analyzing network traffic. In almost all forensic fields, the use of statistical and machine-learning tools is now used to supplement, rather than supplant, human examiner judgment, and this like the algorithmic risk-assessment debates elsewhere in criminal justice also has concerns regarding transparency and validation.^{75 76}

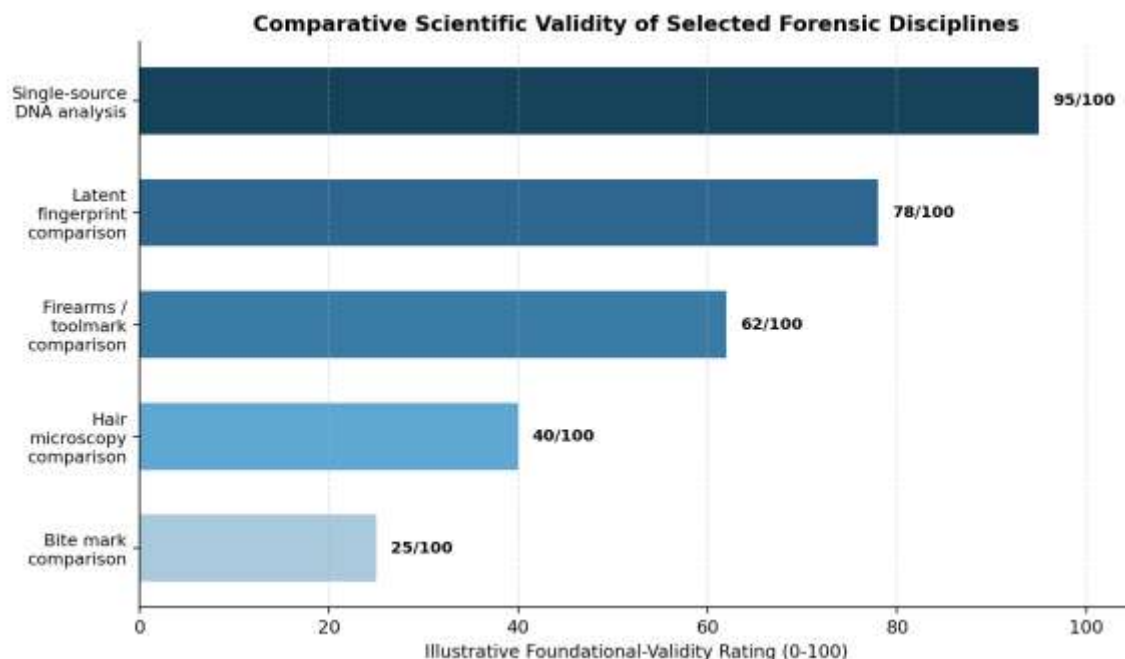


Figure 1. Comparative scientific validity of selected forensic disciplines, based on National Academy of Sciences and PCAST review findings.

The chart above places several forensic disciplines on an illustrative continuum defined by the degree of empirical validation that is reported in the two National Academy of Sciences and PCAST reviews described in Section 8. Single-source DNA analysis is at the high end of the scale, with extensive black-box testing, and a reliable connection repeatedly demonstrated in scientific reviews and specific exoneration cases, while bite mark comparison is at

the low end of the scale, and despite repeated failures to establish a reliable connection between a bite mark and a specific dentition, it is still used as proof of identity. The middle position of fingerprint and firearms comparison is due to techniques that have been in use for a long time and have given good results in investigations, but have only been gradually and in part quantified in terms of error rates. These ratings are intended to provide an illustration and not a precise

⁷³David H. Kaye, *The Double Helix and the Law of Evidence* (Harvard University Press, 2010).

⁷⁴Jay D. Aronson, *Genetic Witness: Science, Law, and Controversy in the Making of DNA Profiling* (Rutgers University Press, 2007).

⁷⁵Michael J. Saks & Jonathan J. Koehler, "The Coming Paradigm Shift in Forensic Identification Science," *Science* 309, no. 5736 (2005): 892.

⁷⁶Jonathan J. Koehler, "Fingerprint Error Rates and Proficiency Tests: What They Are and Why They Matter," *Hastings Law Journal* 59, no. 5 (2008): 1077.

measure as the reliability of a sample will depend on its quality, training of the examiner and the sample handling procedure in each case.

XI. THE INDIAN FORENSIC FRAMEWORK

In the last few decades, the forensic infrastructure in India has grown significantly with the establishment of a network of Central and State Forensic Science Laboratories under the Directorate of Forensic Science Services and other dedicated academic and research institutions like the National Forensic Sciences University in Gandhinagar which has been set up specifically to develop the capacity in the field.⁷⁷ The Bureau of Police Research and Development assists and trains state police forces and conducts standardisation; the National Crime Records Bureau maintains statistics on crime at the national level and notes that the level of detail in the available forensic performance data is not as detailed as in other jurisdictions like the United States and the United Kingdom, and that such data is increasingly being incorporated into these national crime statistics.^{78 79}

Since then, legislative reform has gone much the same as in criminal procedure, overall. The Bharatiya Sakshya Adhiniyam, 2023, a reworking of the Indian evidence law modernised a number of provisions involving expert opinion and electronic evidence without introducing any significant amendment to the basic concept of reliance being examined by the court instead of any kind of formal pre-admission scientific gatekeeping test adopted in American federal courts, as originally envisioned by Frye. Specific cases have also led to reform pressure, for instance, the Justice Verma Committee's report on the Delhi gang-rape case in 2013 called for a better forensic approach to the investigation of sexual assaults, which included

prompt collecting of evidence, and training of examining personnel.⁸⁰ The long awaited DNA Technology (Use and Application) Regulation Bill, which aims to establish a national DNA database and a uniform system of accreditation of laboratories and quality control systems, is a good example of the direction of travel as well as the practical challenges of drafting a comprehensive DNA regulation bill that has languished in the legislative assembly for several years without enactment.⁸¹ The Supreme Court's decision in *Selvi v. State of Karnataka* is another example of how Indian law face head on and gingerly the dilemma between the investigative utility of the new forensic and neuro-scientific techniques and constitutional rights owed to the people subjected to them.

XII. CONCLUSION

Confession and witness testimony can no longer do all the things forensic science can: A blood stain, a fingerprint, a piece of DNA, a deleted file, can all testify to events witnessed by neither living nor willing witnesses. That has been a power that has made it much easier to be correct in both convictions and, in particular, corrections of some of the worst mistakes by the criminal justice system in the past, thanks to post-conviction DNA testing.

Its continued problem is to keep all its branches - including the newest - at the same degree of empirical testing as DNA analysis. The National Academy of Sciences and PCAST reviews were not an attack on forensic science, but rather a request that the public trust of forensic science be matched, discipline by discipline, technique by technique, with a high and reliable level of public trust. That match and the procedural safeguards which are essential – such as the

⁷⁷National Forensic Sciences University, Gandhinagar, Government of India, nfsu.ac.in (accessed 2026).

⁷⁸Bureau of Police Research and Development, Ministry of Home Affairs, Government of India, bprd.nic.in (accessed 2026).

⁷⁹National Crime Records Bureau, Government of India, "Crime in India," annual report series, ncrb.gov.in (accessed 2026).

⁸⁰Justice J. S. Verma Committee, Report of the Committee on Amendments to Criminal Law (New Delhi, 2013), on forensic and procedural reform following the 2012 Delhi gang-rape case.

⁸¹The DNA Technology (Use and Application) Regulation Bill, 2019 (India) (pending enactment).

continuity of custody, accredited laboratories, and context-blind examination – will be the ones that will determine whether forensic science maintains the trust of courts, investigators and the public.