ROLE OF FORENSIC SCIENCE IN CRIMINAL INVESTIGATION

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ABSTRACT

Forensic science has emerged as an indispensable component of the modern criminal justice system by integrating scientific methods into criminal investigation and adjudication. It has transformed the investigative process from one predominantly dependent on confessions and eyewitness testimony to one founded on objective, reliable, and scientifically verifiable evidence. This paper examines the evolving role of forensic science in criminal investigation, with particular emphasis on its contribution to evidence collection, identification of offenders and victims, crime scene reconstruction, corroboration of prosecution evidence, prevention of wrongful convictions, and protection of fair trial rights. It analyses important forensic techniques such as fingerprinting, DNA profiling, cyber forensics, forensic odontology, voice print analysis, photographic superimposition, and scientific interrogation methods including narco-analysis, polygraph examination, and brain mapping.

The paper further explores the constitutional and evidentiary dimensions governing forensic evidence in India by examining significant judicial pronouncements, including *Selvi v. State of Karnataka*, *Mukesh v. State (NCT of Delhi)*, *Manoj v. State of Madhya Pradesh*, and other recent decisions. It also discusses the impact of the Bharatiya Sakshya Adhiniyam, 2023, in recognising scientific and electronic evidence while preserving judicial scrutiny over expert testimony. The study highlights that although forensic science significantly enhances the accuracy, transparency, and credibility of criminal investigations, its effectiveness depends upon proper collection, preservation, chain of custody, expert competence, and adherence to constitutional safeguards.

The paper concludes that forensic science is not merely an investigative aid but a vital instrument for ensuring both effective law enforcement and the protection of individual rights. However, persistent challenges such as inadequate forensic infrastructure, shortage of trained experts, delays in laboratory analysis, and concerns regarding standardisation and institutional independence continue to impede its full potential. Strengthening forensic capacity through legal reforms, technological advancement, specialised training, and independent forensic institutions is essential for ensuring fair, efficient, and evidence-based criminal justice in India.

1. Introduction

The criminal justice system, in all civilizations, has always depended on reliable methods of proof to distinguish truth from falsehood. In earlier times, decisions were often based on confessions, beliefs, or oral statements. In modern legal systems, however, this role is increasingly performed by forensic science, which provides objective and scientific methods to assist courts in finding the truth.

The word "forensic" is derived from the Latin term *forensis*, which means "of the forum." In ancient Rome, the *forum* was a public place where legal disputes were argued and decided. Evidence was presented openly, and reasoning played a central role in resolving disputes. This historical practice laid the foundation for the present-day connection between law and scientific evidence, where facts must be proved through rational and verifiable means.[1]

In its modern sense, forensic science refers to the application of scientific principles to legal issues, especially in criminal investigation and trial. The growth of forensic science reflects a shift from superstition-based and confession-oriented justice to a system based on evidence, logic, and scientific reasoning. Early forms of forensic practices can be traced to ancient civilizations. For example, fingerprints were used in China as early as 700 A.D. for identifying individuals, while Roman and Arab legal systems recorded the use of medical examinations to determine causes of injury and death.[2]

Forensic science developed as an independent discipline during the late nineteenth and early twentieth centuries. Significant progress was made in areas such as pathology, toxicology, and criminal anthropology. A major milestone was the publication of Hans Gross's book *Criminal Investigation* (1893)[3], which was a foundational text in forensic science, pioneering systematic criminal investigation by integrating diverse scientific fields like physics, chemistry, and microscopy with psychological insights into crime scenes, witnesses, and criminals, aiming to provide practical guidance for magistrates and police beyond mere legal codes, emphasizing objective observation of physical evidence and human behaviour and explained how scientific

[1] Upendra Singh Jandu, *Forensic Science and Criminal Justice System In India* 3–4 (LexisNexis 2018).
[2] Ibid.
[3] Hans Gross's *Criminal Investigation* (original German title: *Handbuch für Untersuchungsrichter als System der Kriminalistik*, 1893) is a foundational text that established the field of scientific crime detection, earning Gross the title "Father of Criminalistics". It introduced systematic, scientific methods for analysing crime scenes, emphasizing trace evidence such as blood, hair, and fibres.

methods could be systematically used in criminal investigations. During the twentieth century, forensic laboratories were established, fingerprint classification systems were standardised, and blood and body fluid analysis (serology) became common. The most revolutionary development came in 1985, when Sir Alec Jeffreys **(**a British geneticist known for developing techniques for genetic fingerprinting and DNA profiling which are now used worldwide in forensic science to assist police detective work and to resolve paternity and immigration disputes) discovered DNA fingerprinting. DNA profiling brought a new level of accuracy in identifying individuals and completely transformed criminal investigations worldwide.[4]

In India, forensic science developed during the colonial period with the establishment of fingerprint bureaus, chemical examiner laboratories, and medico-legal practices. After independence, the importance of forensic science increased significantly due to the rise in organised crime, sexual offences, terrorism, and later cybercrime.[5] Courts began to rely more heavily on scientific evidence, which led to judicial examination of its admissibility, reliability, and constitutional limits, particularly in relation to personal liberty and fair trial rights.

In the twenty-first century, forensic science has expanded far beyond traditional techniques. Modern investigations now make use of advanced DNA technologies, cyber and digital forensics, voice print analysis, forensic odontology, photographic superimposition, and neuro-forensic methods such as brain mapping. These advancements have greatly improved the accuracy and speed of criminal investigations. At the same time, they have raised serious legal and ethical concerns relating to privacy, bodily autonomy, protection against self-incrimination, and the right to a fair trial. Therefore, while forensic science strengthens the justice system, it also requires careful legal regulation and judicial scrutiny.[6]

2. Role of Forensic Science in Criminal Investigation

Forensic science plays a foundational role in the criminal investigation process by bridging the gap between suspicion and proof. Modern criminal investigations increasingly rely on forensic methods to ensure objectivity, accuracy, and scientific neutrality, thereby reducing dependence on confessions and eyewitness testimony, which are often unreliable. Scholars have observed that the evolution of forensic science reflects a broader transition from confession-based

[4] BR Sharma, *Forensic Science in Criminal Investigation and Trials* 1-5 (5th ed., Universal Law Publishing 2016)
[5] Ibid.
[6] R. Ramachandran, *Scientific Techniques in Criminal Investigation*, 62-63 (2nd ed., Lawmann's 2023).

policing to evidence-based adjudication, strengthening procedural fairness and investigative accountability.[7] Comparative jurisprudence illustrates this evolution. In the United States, courts developed standards to determine when scientific evidence can be accepted in criminal trials. In *Frye v. United States* [8], the Court held that scientific evidence is admissible only if the technique is generally accepted by the relevant scientific community. Later, in *Daubert v. Merrell Dow Pharmaceuticals*[9], this approach was refined by placing a greater responsibility on judges to act as "gatekeepers." Under *Daubert*, courts must independently assess the reliability of scientific evidence by examining factors such as the validity of the methodology, whether it has been tested and peer-reviewed, and its potential error rates, rather than relying solely on expert consensus. This evolution reflects a shift from passive acceptance of expert opinion to active judicial scrutiny, a principle that also informs contemporary Indian jurisprudence on forensic evidence. A similar evolution is evident in Indian jurisprudence, where the Supreme Court has encouraged scientific investigation while insisting on constitutional safeguards. In *Selvi v. State of Karnataka*,[10] coercive techniques were rejected, but non-intrusive forensic methods were upheld, and in *Mukesh v. State (NCT of Delhi)*,[11] DNA evidence was relied upon to strengthen the prosecution case. Recently in *Amlesh kumar v. State of Bihar,*[12] the Supreme Court reinforced that coerced forensic testing violates the right against self-incrimination under Article 20(3)) and personal liberty under Article 21. At the same time, decisions such as *Pattu Rajan v. State of Tamil Nadu*[13] reiterate that expert evidence cannot replace judicial reasoning, reflecting India's shift toward evidence-based policing under strict judicial scrutiny.

2.1 From Crime Scene to Courtroom

The role of forensic science commences at the crime scene, where scientific techniques are employed to locate, collect, preserve, and analyse physical and digital evidence. DNA profiling, fingerprint examination, bloodstain pattern analysis, cyber forensics, and forensic photography assist investigators in reconstructing events and establishing links between the

[7] BR Sharma, *Forensic Science in Criminal Investigation and Trials* 21-26 (5th edn, Universal Law Publishing 2016)
[8] *Frye v. United States* 293 F. 1013 (D.C. Cir. 1923)
[9] *Daubert v. Merrell Dow Pharmaceuticals* 509 US 579 (1993)
[10] *Selvi v State of Karnataka* (2010) 7 SCC 263
[11] *Mukesh v State (NCT of Delhi)* (2017) 6 SCC 1
[12] *Amlesh kumar v. State of Bihar* 2025 INSC 810
[13] *Pattu Rajan v. State of Tamil Nadu* (2019) 4 SCC 771

crime, victim, and accused. Proper crime scene management and maintenance of the chain of custody are indispensable to ensure evidentiary integrity and admissibility.

The Supreme Court has repeatedly stressed that lapses in evidence collection may fatally weaken prosecution cases. In *Manoj v State of Madhya Pradesh*,[14] the Court issued comprehensive directions mandating scientific crime scene investigation and forensic involvement in serious offences, recognising that delayed or improper forensic processing undermines criminal trials. Critical flaws in forensic evidence handling were also highlighted. The Court further directed States to establish dedicated forensic units and ensure early deployment of forensic experts.

Similarly, in *Satish v State of Haryana*,[15] the Court highlighted the importance of prompt forensic examination in sexual offence cases and criticised investigative failures where biological samples were not preserved scientifically.

2.2 Identification of Accused and Victims

Forensic science plays a decisive role in identifying unknown accused persons and victims. DNA fingerprinting, forensic odontology, voice print analysis, and photographic superimposition enable identification in cases involving mutilated bodies, mass disasters, sexual offences, and organised crime. Teeth, being highly resistant to destruction, often provide the only reliable means of identification in charred or decomposed bodies.

Indian courts have recognised that scientific identification significantly reduces the risk of wrongful conviction. In *Mukesh v State (NCT of Delhi)*,[16] DNA evidence conclusively connected the accused to the crime, reinforcing eyewitness testimony and medical findings. Likewise, in *Krishan Kumar Malik v State of Haryana*,[17] the Court emphasised that DNA profiling offers near-conclusive identification when properly conducted.

Forensic odontology and bite-mark evidence have also been judicially noticed, though courts caution that such evidence must be corroborative rather than standalone.

[14] *Manoj v State of Madhya Pradesh* (2023) 2 SCC 353
[15] *Satish v State of Haryana* (2021) 6 SCC 1
[16] *Mukesh v State (NCT of Delhi)* (2017) 6 SCC 1
[17] *Krishan Kumar Malik v State of Haryana* (2011) 7 SCC 130

2.3 Scientific Corroboration and the Exclusionary Function of Forensic Evidence

One of the most significant contributions of forensic science to criminal adjudication lies in its dual capacity to corroborate prosecution evidence and exclude innocent persons from suspicion. Unlike testimonial evidence, which is vulnerable to human error, coercion, or bias, forensic evidence offers an objective scientific basis for reconstructing crime events. Techniques such as DNA profiling, fingerprint analysis, and forensic pathology can conclusively establish the presence of an accused at a crime scene or, equally importantly, eliminate suspects who have been wrongly implicated.

The Supreme Court has repeatedly emphasised the corroborative role of forensic evidence. In *Mukesh v. State (NCT of Delhi)*,[18] DNA and medical evidence strongly supported eyewitness accounts, thereby reinforcing the prosecution narrative and ensuring that conviction was grounded in scientific certainty rather than mere testimony. This approach reflects judicial awareness of the dangers of relying solely on oral evidence in serious criminal trials.

Equally vital is the exclusionary value of forensic science. Courts have recognised that inconsistencies or absence of scientific evidence may expose investigative lapses and wrongful implication. In *Manu Sharma v. State (Jessica Lal Murder case)*,[19] the Supreme Court critically examined deficiencies in evidence collection and highlighted how investigative failures can undermine the integrity of criminal trials. This reasoning was reaffirmed in *Santosh Kumar Singh v. State (Priyadarshini Mattoo case)*,[20] where forensic shortcomings prompted judicial scrutiny of police conduct and contributed to appellate reassessment of the case.

These decisions demonstrate a growing judicial sensitivity towards the protective function of forensic science. Scientific evidence is no longer viewed merely as a tool for securing convictions, but also as a safeguard against miscarriages of justice. By enabling both confirmation and exclusion, forensic science strengthens the presumption of innocence and promotes fairness in criminal proceedings. However, courts continue to caution that forensic evidence must be properly collected, preserved, and interpreted, and must always be subjected to rigorous judicial scrutiny to prevent over-reliance on expert opinion.

[18] *Mukesh v State (NCT of Delhi)* (2017) 6 SCC 1
[19] *Manu Sharma v. State* (2008) 5 SCC 230
[20] *Santosh Kumar Singh v State* (2010) 9 SCC 747

2.4 Transition from Confession-Based Policing

Historically, criminal investigations in India often relied on custodial confessions and informal evidence gathering, a practice that frequently led to coercion, violations of personal liberty, and compromised fairness. The constitutional shield under Article 20(3)**,** the right against self-incrimination, has been a critical bulwark against compelled testimonial confessions that derive from custodial pressure.[21] However, the increasing role of forensic science marks a decisive shift toward evidence-based policing, where objective scientific methods support investigative findings and reduce dependence on unverified human testimony.

A key judicial watershed in this transition was the Supreme Court's pronouncement in *Selvi v State of Karnataka*,[22] where the Court held that coercive techniques such as narco-analysis, brain mapping, and polygraph cannot be administered without consent as they violate Articles 20(3) and 21 of the Constitution. The judgment firmly separated testimonial compulsion from legitimate forensic processes involving physical samples. The Court emphasised that while confessions extracted under duress are constitutionally forbidden, the collection of physical evidence such as fingerprints and DNA samples is permissible where legally justified.

Post-2020 jurisprudence continues to reinforce this approach. For example, in *Karandeep Sharma @ Razia @ Raju v State of Uttarakhand*,[23] the Supreme Court overturned a death sentence because the prosecution failed to examine the scientific expert who conducted the DNA profiling; it underscored that DNA reports cannot be admitted as a "black-box" substitute for expert testimony, and that both chain of custody and expert presence in court are essential for admissibility. This reflects judicial insistence on procedural integrity rather than blind acceptance of scientific outputs.

In a contemporaneous development, the Supreme Court in *Kattavellai @ Devakar v State of Tamil Nadu*[24] issued detailed guidelines on DNA sample collection and handling, emphasizing proper documentation, timely transport to forensic labs, and maintaining the scientific sanctity of evidence. These directions are aimed at institutionalising rigorous forensic methods and

[21] *Selvi v State of Karnataka* (2010) 7 SCC 263 (recognising Article 20(3) protection against coercive techniques).
[22] Ibid
[23] *Karandeep Sharma @ Razia @ Raju v State of Uttarakhand* (2025) INSC 444
[24] *Kattavellai @ Devakar v State of Tamil Nadu* 2025 INSC 845

ensuring that scientific evidence strengthens rather than undermines justice.

The Court has also advanced scientific investigation in other realms. In *Rahul Agarwal v State of West Bengal*,[25] the Supreme Court clarified that a Magistrate may order collection of voice samples from not only accused persons but also witnesses, holding that such samples are material evidence and do not violate the protection against self-incrimination under Article 20(3). This ruling builds upon *Ritesh Sinha v State of Uttar Pradesh*[26], where the Court held that voice samples, like fingerprints and handwriting specimens, are physical characteristics and thus admissible in criminal investigation without violating constitutional rights. The recent order directing the National Forensic Science University (NFSU) to examine audio recordings in the Manipur ethnic violence case further highlights the judiciary's reliance on forensic analysis in complex matters of public importance.[27]

These judicial trends illustrate a broader paradigm shift in Indian criminal justice: forensic science is no longer peripheral but central to modern investigation. The courts insist on scientifically valid evidence that meets constitutional safeguards and procedural rigour, thereby reducing reliance on confessions that are susceptible to error or coercion. However, judicial vigilance remains crucial; forensic tools must be deployed in ways that respect individual rights, maintain evidentiary integrity, and ensure that science serves justice rather than becoming a source of injustice.

2.5 Forensic Science and Fair Trial Guarantees

Forensic science supports fair trial guarantees by helping courts convict the guilty while protecting the innocent through objective scientific evidence such as DNA and digital forensics. However, the Supreme Court has cautioned that expert evidence cannot be accepted blindly and must be corroborated with other material on record.[28] In *Mukesh v State (NCT of Delhi)*,[29] forensic findings strengthened the prosecution only after procedural compliance was verified. Recent decisions like *Karandeep Sharma v State of Uttarakhand*[30] reaffirm that DNA reports without proper chain of custody or expert examination violate Article 21. While the

[25] *Rahul Agarwal v State of West Bengal* 2025 INSC 1223
[26] *Ritesh Sinha v State of Uttar Pradesh* (2019) 8 SCC 1
[27] https://www.livelaw.in/top-stories/manipur-violence-supreme-court-orders-forensic-examination-of-entire-audio-clip-admitted-voice-recordings-of-ex-cm-biren-singh-517197
[28] *State of H.P. v Jai Lal* (1999) 7 SCC 280
[29] *Mukesh v State (NCT of Delhi)* (2017) 6 SCC 1
[30] *Karandeep Sharma @ Razia @ Raju v State of Uttarakhand* (2025) INSC 444

Bharatiya Sakshya Adhiniyam, 2023 gives statutory recognition to forensic evidence, judicial scrutiny remains the ultimate safeguard against misuse.

2.6 Forensic Science and Wrongful Convictions

One of the most critical yet often underemphasized roles of forensic science lies in its capacity to prevent and correct wrongful convictions. Wrongful convictions frequently arise from unreliable eyewitness testimony, coerced confessions, investigative bias, and improper forensic practices. Scientific evidence, when properly collected and interpreted, serves as a corrective mechanism against such miscarriages of justice.

DNA profiling has played a transformative role in post-conviction exonerations across jurisdictions. In the United States, the work of the Innocence Project[31] has demonstrated that DNA evidence has been instrumental in overturning numerous wrongful convictions, particularly in cases involving mistaken identity and false confessions. These developments underscore the exculpatory potential of forensic science when deployed with methodological rigor.

Indian courts have increasingly acknowledged the exclusionary value of forensic evidence. In *Santosh Kumar Singh v. State (Priyadarshini Mattoo Case)*[32], forensic inconsistencies contributed to appellate scrutiny of investigative lapses. Similarly, judicial emphasis on scientific corroboration in cases such as *Mukesh v. State (NCT of Delhi)*[33] reflects awareness of the dangers of conviction based solely on testimonial evidence.

However, the relationship between forensic science and wrongful convictions is not unidirectional. Faulty forensic techniques, unvalidated methods, and overstatement of expert conclusions have also contributed to wrongful convictions internationally. Reports such as the United States National Academy of Sciences (2009)[34] have exposed systemic weaknesses in several forensic disciplines, including bite mark analysis and hair comparison. These findings highlight the necessity of rigorous standards, continuous validation, and judicial vigilance.

[31] The Innocence Project is a national litigation and public policy organization dedicated to exonerating wrongfully convicted people through DNA testing and reforming the criminal justice system to prevent future injustice.
[32] Santosh Kumar Singh vs. State (2010) 3 SCC (Cri) 1469
[33] *Mukesh v. State (NCT of Delhi)* (2017) 6 SCC 1
[34] National Research Council, *Strengthening Forensic Science in the United States: A Path Forward*, National Academy of Sciences, Washington DC, 2009.

Therefore, while forensic science possesses immense potential to prevent wrongful convictions, its effectiveness depends on proper training, standardization, transparency, and adversarial testing within the courtroom. Courts must remain alert to both the strengths and limitations of forensic evidence to ensure that scientific advancement strengthens rather than undermines justice.

3. Some Techniques Used in Forensic Science

Forensic science has emerged as one of the most crucial pillars of the modern criminal justice system. It represents the intersection of law and science, where scientific techniques are applied to investigate crimes, identify offenders, and assist courts in arriving at the truth. In recent decades, rapid technological advancements have transformed traditional forensic methods into highly sophisticated tools capable of uncovering complex forms of evidence. Modern forensic science encompasses a wide range of disciplines, including fingerprinting, DNA profiling, toxicology, cyber forensics, forensic odontology, voice analysis, and photographic techniques. These methods assist investigators in identifying suspects, reconstructing crime scenes, corroborating testimony, and excluding innocent persons. Importantly, forensic science plays a dual role, strengthening prosecution cases while simultaneously safeguarding against wrongful convictions.

These developments have significantly influenced investigation, prosecution, and adjudication of criminal cases.

3.1. Fingerprinting

Fingerprinting is one of the earliest and most trusted scientific methods used for identifying individuals in criminal investigations. The technique is based on a well-established scientific principle that the ridge patterns found on human fingertips are unique to every individual and do not change from birth until death, except in cases of serious injury. These ridge patterns are formed by alternating raised lines (ridges) and depressions (furrows) on the skin of the fingertips. On the basis of their overall structure, fingerprints are broadly classified into three basic patterns, namely loops, whorls, and arches, which further assist experts in classification and comparison.

In the context of criminal investigation, fingerprints are frequently recovered from crime scenes

in different forms depending on the surface and the substance involved. Many fingerprints are not visible to the naked eye and are known as latent fingerprints; these are usually developed by forensic experts using powders, chemical reagents, or advanced lighting techniques. Some fingerprints are clearly visible because they are made with substances such as blood, ink, grease, or paint, and these are referred to as patent fingerprints. In certain cases, fingerprints are left as impressions on soft surfaces such as wax, clay, soap, or wet cement, and these are described as plastic fingerprints. Each type of fingerprint has evidentiary value and can be scientifically examined and compared with known samples.

Fingerprint evidence plays a crucial role in establishing the identity of an accused person and linking them to the scene of crime. Because the process of fingerprint collection and comparison is relatively simple, inexpensive, and highly reliable, it has become a routine and indispensable part of police investigation. Over decades, fingerprinting has gained strong judicial acceptance in India. Courts have consistently treated fingerprint evidence as expert evidence, earlier under Section 45 of the Indian Evidence Act, 1872, and now under the corresponding provisions (Section 39) of the Bharatiya Sakshya Adhiniyam, 2023.

The constitutional validity of fingerprinting has also been clearly upheld by the Supreme Court. In *State of Bombay v. Kathi Kalu Oghad*,[35] the Court held that the taking of fingerprints does not amount to testimonial compulsion and therefore does not violate the right against self-incrimination guaranteed under Article 20(3) of the Constitution. The Court clarified that fingerprints are physical or identifying evidence, not personal testimony. This judicial reasoning continues to guide the admissibility of fingerprint evidence under the new evidence law, reinforcing its importance as a reliable forensic tool in the administration of criminal justice.

3.2. DNA Fingerprinting (DNA Profiling)

DNA evidence refers to biological material containing Deoxyribonucleic Acid (DNA) that is collected from crime scenes, victims, or accused persons and scientifically analysed to assist courts in determining facts such as identity, involvement in a crime, or biological relationships. Successful identification of skeleton remains can also be performed by DNA profiling. DNA is present in almost every cell of the human body and is unique to each individual, except

[35] State of Bombay v. Kathi Kalu Oghad AIR 1961 SC 1808

identical twins. Because of this unique nature, DNA evidence is regarded as one of the most reliable forms of forensic evidence in modern criminal justice systems. However, DNA evidence does not directly prove guilt; rather, it functions as strong circumstantial scientific evidence that connects a person to a crime scene, victim, or object. In *Dharam Deo Yadav vs State of U.P.*[36] , the Supreme Court upheld the conviction of a Varanasi tour guide for the 1997 murder of New Zealand tourist Diana Clare Routley based on circumstantial evidence and DNA evidence.

The origin of DNA evidence as a forensic tool can be traced to developments in molecular biology during the twentieth century. DNA was first identified in 1869 by Friedrich Miescher, but its significance was fully understood only after James Watson and Francis Crick discovered its double-helix structure in 1953. The real forensic breakthrough came in 1985, when Sir Alec Jeffreys developed DNA fingerprinting in the United Kingdom. He demonstrated that certain regions of DNA vary greatly between individuals and could be used for personal identification. DNA evidence was first used in criminal investigation in the Enderby murders in England[37], where it not only identified the true offender but also exonerated an innocent suspect (Colin Pitchfork and Richard Buckland respectively). This case established DNA evidence as a powerful tool for both conviction and exoneration, leading to its rapid global acceptance.

DNA fingerprinting, also known as DNA profiling, is a modern forensic technique that identifies individuals based on their unique genetic makeup. DNA (Deoxyribonucleic Acid) is present in almost every cell of the human body and carries hereditary information. DNA fingerprinting examines specific regions of DNA, such as Short Tandem Repeats (STRs), which vary greatly among individuals and therefore act as a genetic identifier, similar to a biological barcode. DNA suitable for forensic examination can be obtained from various biological sources, including blood, semen, saliva, hair with roots, skin cells, bone, and teeth. These materials are often recovered from clothing, weapons, bodies of victims or accused persons, and crime scenes.[38]

The process of analysing DNA evidence involves several scientific steps. First, biological samples are carefully collected and preserved to prevent contamination. DNA is then extracted

[36] Dharam Deo Yadav vs State of U.P. (2014) 5 SCC 509
[37] R v Pitchfork [2009] EWCA Crim 963; see also R v Pitchfork (1988) 90 Cr App R 220 (first criminal case using DNA profiling)
[38] R. Ramachandran, *Scientific Techniques in Criminal Investigation*, 119-121 (2nd ed. 2023).

from the cells, quantified to determine the amount available, and amplified using the Polymerase Chain Reaction (PCR) technique. The amplified DNA fragments are analysed to create a DNA profile, which is then compared with reference samples from suspects or databases. The reliability of DNA evidence depends greatly on proper sample handling, laboratory standards, and an unbroken chain of custody.

DNA evidence plays a crucial role in criminal investigations by helping to identify perpetrators, link accused persons to crime scenes, corroborate victim testimony, and exclude innocent suspects. It has proved especially valuable in cases of sexual offences, homicide, terrorism, missing persons, and mass disasters. Unlike confessions or eyewitness accounts, which may be influenced by coercion or error, DNA evidence provides objective scientific support to the investigative process. Now, for several years, DNA profile has shown a tremendous impact on forensic investigation. Generally, when DNA profile of a sample found at the scene of crime matches with the DNA profile of the suspect, it can generally be concluded that both the samples have the same biological origin. DNA profile is valid and reliable, but variance in a particular result depends on the quality control and quality procedure in the laboratory.[39]

In India, DNA evidence is treated as expert evidence under Section 45 of the Indian Evidence Act, 1872, and continues to receive statutory recognition under the Bharatiya Sakshya Adhiniyam, 2023, which strengthens the admissibility of scientific and electronic evidence. Courts do not treat DNA evidence as conclusive proof and insist on examining its reliability, methodology, and compliance with procedural safeguards. Proper collection, lawful sampling, competent expert testimony, and adherence to scientific protocols are essential conditions for admissibility.

DNA evidence raises important constitutional issues, particularly concerning the right against self-incrimination under Article 20(3) and the right to privacy under Article 21 of the Constitution. In *State of Bombay v. Kathi Kalu Oghad*[40], the Supreme Court clarified that providing physical evidence such as fingerprints or DNA samples does not amount to testimonial compulsion. Hence, the taking and retention of DNA samples which are in the nature of physical evidence do not face Constitutional hurdles.[41] However, DNA testing does

[39] *Anil @ Anthony Arikswamy Joseph Vs. State of Maharashtra* (2014) 4 SCC 69
[40] *State of Bombay v. Kathi Kalu Oghad* AIR 1961 SC 1808 (holding that fingerprints, handwriting, and similar physical evidence are not testimonial in nature)
[41] *Selvi v. State of Karnataka* AIR 2010 S.C. 1974

affect bodily integrity and informational privacy. After the landmark decision in *Justice K.S. Puttaswamy v. Union of India*[42], courts now apply the tests of legality, necessity, and proportionality before directing DNA tests.

Indian courts have consistently recognised the probative value of DNA evidence. In *Krishan Kumar Malik v. State of Haryana*[43], the Supreme Court stressed the importance of DNA testing in rape cases and observed that failure to conduct such tests could weaken the prosecution case. In *Mukesh v. State (the Nirbhaya case)*[44], DNA evidence played a decisive role in conclusively establishing the guilt of the accused. At the same time, courts have cautioned against mechanical reliance on DNA evidence without corroboration and proper safeguards. More recently, *Ashok Kumar v. Raj Gupta*[45] reaffirmed that courts may direct DNA testing when necessary to arrive at the truth, subject to proportionality and privacy considerations under Article 21.

DNA evidence has also played a vital role in preventing and correcting wrongful convictions. By objectively establishing innocence, DNA profiling has helped overturn convictions based on faulty investigations, false confessions, or unreliable eyewitness testimony. Internationally, DNA evidence has been central to the work of Innocence Projects, particularly in the United States. However, misuse, contamination, laboratory errors, or improper interpretation of DNA evidence can themselves lead to miscarriages of justice if adequate safeguards are not maintained. DNA evidence must be properly documented, collected, packaged, and preserved to meet legal and scientific standards for admissibility in court. Since even very small DNA samples can be analysed, there is a high risk of contamination if proper precautions are not followed. Contamination may occur when DNA from another source mixes with the relevant sample, for example, through coughing, sneezing, or careless handling of evidence.[46] Although DNA evidence plays an important role in criminal investigations, it does not automatically establish identity in court unless supported by proper procedure, expert opinion, and corroborative evidence.

[42] *Justice K.S. Puttaswamy (Retd.) v. Union of India* (2017) 10 SCC 1
[43] *Krishan Kumar Malik v. State of Haryana* (2011) 7 SCC 130
[44] *Mukesh v. State (NCT of Delhi)* (2017) 6 SCC 1
[45] *Ashok Kumar v. Raj Gupta* (2022) 1 SCC 20
[46] *Rahul vs State of Delhi* (2023) 1 SCC83

3.3. Footprints

Footprints constitute an important form of impression evidence in criminal investigation, often providing valuable clues regarding the presence, movement, and identity of a suspect at or near the scene of crime. Footprints may be visible (patent)[47] or latent (hidden)[48] and can be left on surfaces such as soil, sand, dust, blood, or floors. Forensic examination of footprints involves analysing size, shape, ridge patterns, gait characteristics, and unique features such as scars or deformities. Footprint evidence can help estimate height, weight, direction of movement, and even the number of persons involved. When properly photographed, cast, and preserved, footprints may be compared with the suspect's footprints to establish identity. Indian courts treat footprint evidence as corroborative in nature, requiring it to be supported by other circumstantial or scientific evidence. Its probative value depends largely on proper collection, expert analysis, and maintenance of chain of custody.

Indian courts have recognised footprint evidence as a form of circumstantial and expert evidence, admissible under Section 45 of the Indian Evidence Act, 1872 (now Bharatiya Sakshya Adhiniyam, 2023), provided it is properly collected and corroborated.

In *Ramesh Chandra Agrawal v. Regency Hospital Ltd.*[49] the Supreme Court observed that expert evidence must assist the court and cannot replace judicial reasoning, a principle equally applicable to footprint comparison. In *Jaspal Singh v. State of Punjab*[50], footprint evidence was accepted as corroborative material linking the accused to the scene, though the Court cautioned that such evidence cannot be the sole basis for conviction. Similarly, in *State of U.P. v. Ram Babu Misra*[51], the Court stressed that identification through physical impressions requires strict procedural safeguards and expert verification.

3.4. Tyre Marks

Tyre marks are another crucial type of trace evidence frequently encountered in offences

[47] These are clearly visible to the naked eye. They occur when someone steps in a substance like blood, mud, paint, or dust and then walks on another surface. For example, bloody footprints on a floor after a crime are patent footprints.
[48] These are not visible unless special methods are used. They may be left on smooth surfaces such as tiles or polished floors through sweat or natural oils from the foot. Investigators use powders, chemicals, or special lighting to reveal them.
[49] *Ramesh Chandra Agrawal v. Regency Hospital Ltd*(2009) 9 SCC 709
[50] *Jaspal Singh v. State of Punjab* AIR 1979 SC 1708
[51] *State of U.P. v. Ram Babu Misra* (1980) 2 SCC 343

involving vehicles, such as hit-and-run cases, kidnapping, robbery, and murder. Tyre impressions left on soil, mud, sand, or road surfaces can reveal information about the type of vehicle, direction of travel, speed, and braking patterns. Forensic comparison focuses on class characteristics (such as tread design and size) and individual characteristics (such as cuts, wear patterns, or embedded stones). These individual features can sometimes link a specific vehicle to a crime scene. Tyre marks are documented through photography, casting, or lifting techniques and are later compared with test impressions taken from suspect vehicles. Although tyre mark evidence is generally considered circumstantial, when scientifically analysed and corroborated with other evidence, it can significantly strengthen the prosecution case.

Tyre mark evidence is treated as trace evidence and forms part of circumstantial proof. Courts rely on it mainly to corroborate other forensic or ocular evidence.

In *State of Maharashtra v. Mohd. Yakub*[52], the Supreme Court held that physical traces such as vehicle marks can form an important link in the chain of circumstantial evidence when scientifically analysed. In *Kansa Behera v. State of Orissa*[53], the Court reiterated that impression evidence, including tyre marks, must be carefully evaluated and supported by additional material before fixing criminal liability. More recently, courts have emphasized that vehicle-related forensic evidence gains probative value only when properly documented and matched with expert opinion.

Footprint and tyre mark evidence are admissible as corroborative forensic evidence, but Indian courts consistently hold that they cannot independently sustain conviction unless supported by expert analysis and other incriminating circumstances.

3.5. Narco Analysis

Narco-analysis is a forensic test in which a drug (usually sodium pentothal) mixed with distilled water is injected into a person's body through a vein. This mixture is administered intravenously along with dextrose over a period of nearly three hours. The amount of the drug depends on the person's age, sex, health, and physical condition (Generally 3 grams of Sodium Pentathole in 3000 ml. of distilled water) . The injection is given slowly over a few hours by

[52] *State of Maharashtra v. Mohd. Yakub* (1980) 3 SCC 57
[53] *Kansa Behera v. State of Orissa* AIR 1987 SC 1507

an anaesthetist. If the dose is too strong, it may cause coma or even death, so medical supervision is essential.

The drug gradually puts the person into a semi-conscious or hypnotic state. It depresses the central nervous system, lowers blood pressure, and slows the heart rate. In this condition, the person loses normal self-control and becomes less able to think clearly or hide information.

Once the person reaches this stage, the investigating officers ask questions in the presence of doctors. The answers given are recorded on video. Medical staff continuously monitor the person's blood pressure and ECG throughout the test.

The idea behind narco-analysis is that when a person is semi-conscious, their imagination and reasoning are weakened, making it difficult to lie. The person can usually answer only simple questions, and responses are believed to be more spontaneous because the subject cannot consciously manipulate answers. Narco-analysis, also known as the "truth serum test," is based on the belief that when a person is given certain drugs that reduce reasoning power but do not completely affect memory or speech, the person becomes less capable of hiding the truth. These drugs create a "twilight" or semi-conscious state in which the subject loses self-control and may answer questions more freely.[54]

The term narco-analysis was introduced in 1936 to describe the use of narcotic drugs to induce a trance-like condition. Under the influence of such drugs, a person becomes semi-conscious, speaks more easily, and finds it difficult to deliberately lie. The underlying theory is that lying requires imagination and conscious thinking, both of which are weakened during this state. As a result, answers are believed to be more spontaneous and less manipulated. After the test, the person is allowed to rest for two to three hours.

Narco-analysis is conducted only in government hospitals and requires a court order as well as the personal consent of the subject. Medical experts prepare a report based on the session, which may help investigators collect further evidence. However, it is important to note that narco-analysis does not guarantee truthfulness and has serious legal, medical, and ethical concerns.

[54] R. Ramachandran, *Scientific Techniques in Criminal Investigation*, 271 (2nd ed., Lawmann's 2023).

3.6. Polygraph Test

The polygraph test, commonly known as the lie detector test, was developed from early scientific attempts to measure physical changes in the human body while answering questions. Its origin can be traced back to work of Cesare Lombroso, an Italian criminologist, who experimented with a device called the hydrosphygmograph to measure blood pressure and pulse in suspected criminals. Later, psychologist William Marston used similar techniques during World War I in espionage cases. These early experiments laid the foundation for modern polygraph testing.

In 1921, John Larson improved the technique by adding measurement of respiration, and in 1939 Leonard Keeler further developed the machine by including skin conductivity and electrical amplification. These improvements transformed the polygraph into a device capable of recording multiple physiological responses at the same time.

The basic theory behind the polygraph test is that when a person lies, the body shows involuntary physical reactions different from those produced during truthful answers. These reactions are believed to result from emotional stress or anxiety caused by deception.

During a polygraph examination, several instruments are attached to the subject's body to record physiological changes. These include cuffs to measure blood pressure and pulse, tubes to record breathing patterns, and electrodes placed on the skin to detect sweat-related electrical changes. While the examiner asks a series of structured questions, the machine continuously records the subject's responses.

The polygraph measures changes in respiration, blood pressure, heart rate, pulse, and galvanic skin resistance. The examiner then studies these recorded charts and compares responses to control and relevant questions to assess whether the subject is being truthful.

However, polygraph results depend heavily on interpretation and are influenced by factors such as nervousness, fear, mental condition, and examiner skill. Because of these limitations, polygraph testing is not considered scientifically conclusive.

3.6.1. Polygraph Techniques and Procedure

There are three main polygraph examination techniques commonly used by forensic experts.

These are the Relevant–Irrelevant (R–I) technique, the Control Question Technique (CQT), and the Directed Lie Control (DLC) technique.

Relevant–Irrelevant (R–I) Technique

The Relevant–Irrelevant technique is the simplest form of polygraph testing. In this method, the examiner alternates between asking neutral (irrelevant) questions and crime-related (relevant) questions. Irrelevant questions are ordinary in nature, such as the person's name or age, while relevant questions directly concern the offence. The subject's physiological responses to both types of questions are compared. If stronger reactions appear during relevant questions, deception is suspected. However, this method is considered unreliable because innocent persons may also show anxiety when asked crime-related questions.

Control Question Technique (CQT)

The Control Question Technique is the most commonly used polygraph method. It involves three types of questions: relevant questions related to the crime, control questions about general past misconduct, and neutral questions. Control questions are designed to provoke mild stress, such as asking whether the subject has ever lied to avoid trouble. The theory is that a truthful person reacts more to control questions, while a guilty person reacts more to relevant questions. The examiner compares physiological responses to determine deception. Despite wider use, this method is criticised for depending heavily on psychological assumptions.

Directed Lie Control (DLC) Technique

In the Directed Lie Control technique, the subject is instructed in advance to deliberately lie while answering certain control questions. These intentional lies create a baseline physiological response. The examiner then compares this with responses to relevant crime-related questions. If reactions are stronger during relevant questions, deception is inferred. This technique aims to standardise reactions but still suffers from limitations due to individual emotional differences.

In all these methods, the examination begins with a pre-test interview. During this stage, the subject is informed about the procedure, and the examiner collects background information to prepare appropriate questions. This step is important because unexpected questions may cause reactions unrelated to lying, which could affect the accuracy of the results.

The examiner must be familiar with the facts of the case. Investigating officers usually provide documents such as the First Information Report (FIR), medico-legal reports, and post-mortem reports so that relevant questions can be framed properly.

Among these methods, the Control Question Technique is the most widely used. In this technique, two types of questions are asked: control questions and relevant questions. Control questions are general and unrelated to the crime but are designed to create mild stress (for example, questions about past minor wrongdoing). Relevant questions directly relate to the offence under investigation.

The subject's physical responses such as heartbeat rate, blood pressure, breathing, and skin conductivity are recorded for both types of questions. These responses are then compared. The theory is that a truthful person will react more strongly to control questions, while a deceptive person will show stronger reactions to relevant questions connected with the crime.[55]

In simple terms, an innocent person finds it easier to answer crime-related questions truthfully but may feel uncomfortable answering control questions. On the other hand, a guilty person feels greater anxiety while answering relevant questions about the offence.

After the test, the examiner assigns numerical values to each response. These values are added together and compared with standard scoring scales to determine whether deception is indicated. However, the results depend greatly on the examiner's skill and the subject's emotional condition, which makes the test scientifically uncertain.

Because nervousness, fear, surprise, or stress can also produce similar physical reactions, polygraph results are not considered conclusive. For this reason, Indian law treats polygraph only as an investigative aid, not as evidence.

3.7. Brain Mapping (Brain fingerprinting)

Brain Mapping or Brain Electrical Activation Profile (BEAP) test is a scientific technique used to determine whether specific information related to a crime is stored in a person's brain. This was discovered by Dr. Samuel Sutton, an American Scientist in 1965. During the test, words, pictures, or sounds connected with key features of the crime are shown to the suspect on a

[55] R. Ramachandran, *Scientific Techniques in Criminal Investigation*, 14-15 (2nd ed., Lawmann's 2023).

computer screen, along with neutral and irrelevant items.

The subject wears a special headband fitted with electrodes, and brain activity is recorded through an EEG machine (An electroencephalogram is a test that measures electrical activity in the brain). If the brain recognises crime-related information that only the offender would know, it produces a distinctive electrical response called the P-300 wave, which appears approximately 300 milliseconds after exposure to familiar stimuli.

A baseline brain activity is first established. If the recorded response rises above this baseline, it indicates that the suspect recognises the information shown. If no such response appears, it suggests that the information is not stored in the person's brain.

Thus, a positive P-300 response implies familiarity with crime-specific details, while a negative response indicates lack of such knowledge. This method is used only to generate investigative leads and cannot independently establish guilt.[56]

The BEAP test focuses on identifying whether crime-related information is stored in a suspect's brain. Its application in criminal investigation is not to precisely identify the culprit, but to scientifically confirm whether the suspect possesses knowledge of salient features of the crime.

The technique operates on the principle that the brain automatically recognises familiar information. When crime-specific stimuli are presented, the brain generates a characteristic electrical response (P-300 wave), which is recorded through an EEG. This response occurs before conscious control can intervene, making manipulation by the subject extremely difficult.

Lawrence Farewel developed this technique called Brain fingerprinting. He explains that brain recognition does not stop at the P300 wave alone. He introduced the concept of MERMER (Memory-and-Encoding-Related Multifaceted Electroencephalographic Response), which represents a longer brain response occurring about 300–800 milliseconds after a stimulus, reflecting deeper cognitive processing[57].

Brain fingerprinting is considered more accurate than conventional lie-detection techniques because it does not rely on emotional responses. Instead, it measures recognition of information already stored in the brain. Research shows that lying requires greater cognitive effort, as the

[56] R. Ramachandran, *Scientific Techniques in Criminal Investigation*, 14-15 (2nd ed., Lawmann's 2023).
[57] Ibid

brain must first recognise the correct answer and then actively suppress it while constructing an alternative response.

Unlike traditional fingerprinting or DNA profiling which compare physical evidence from the crime scene with samples taken from the suspect, brain fingerprinting compares crime-related information with the informational evidence present in the suspect's brain. While physical fingerprints are available in only a small percentage of crimes, the memory of the crime is always present in the offender's brain, making brain fingerprinting potentially valuable as an investigative aid.

However, brain fingerprinting is intended only to assist investigations and cannot, by itself, conclusively establish guilt.

3.8. Legality of Scientific Interrogation Tests in India

The legality of scientific interrogation techniques, namely narco-analysis, polygraph (lie detector) tests, and Brain Electrical Activation Profile (BEAP), commonly known as brain fingerprinting was conclusively examined by the Supreme Court in *Selvi v. State of Karnataka*.[58] These techniques were challenged on the ground that compelling an accused to undergo such tests violates the fundamental rights guaranteed under Articles 20(3) and 21 of the Constitution of India, as well as the protection against coercive police methods under Section 161(2) of the Code of Criminal Procedure. The Court observed that narco-analysis involves the intravenous administration of sodium pentothal or similar drugs, inducing a hypnotic or semi-conscious state in which the subject's capacity for voluntary control is significantly impaired. Polygraph tests require the attachment of instruments such as cardiographs, pneumographs, blood pressure cuffs, and sensitive electrodes to record physiological responses like heart rate, respiration, and perspiration. BEAP or brain fingerprinting involves placing electrodes on the subject's scalp to record electrical brain waves in response to specific stimuli.

The Supreme Court held that involuntary administration of any of these techniques amounts to testimonial compulsion, thereby violating Article 20(3), since the subject is forced to provide personal knowledge-based information. Furthermore, such procedures intrude upon mental privacy, bodily integrity, and personal autonomy, thus infringing Article 21. The Court

[58] *Selvi v. State of Karnataka* AIR 2010 S.C. 1974

emphasised that these tests are not merely physical examinations but involve extraction of cognitive responses and mental contents. Consequently, compulsory administration of these techniques was declared unconstitutional. Even when conducted with consent, the results of these tests are not admissible as substantive evidence, although any material discovered as a consequence of voluntary disclosure may be admissible under Section 27 of the Indian Evidence Act. The judgment thus firmly establishes that narco-analysis, polygraph, and brain fingerprinting may at best serve as investigative aids, but cannot replace conventional evidence, and their use is strictly conditioned by constitutional safeguards of dignity, liberty, and fair trial.

3.9. Photographic Superimposition

Identification of a dead body is an important task in police investigation. While several methods exist, identification becomes difficult when the body is decomposed and only skeletal remains are available. In such cases, the photographic superimposition technique is used, where a photograph of a missing person is superimposed on the recovered skull to establish identity. This method is based on the principle that no two skulls are exactly alike. The technique gained recognition after its successful use in the *Ruxton case* (1935)[59] famously known as 'Jigsaw Murders' case, was amongst one of the first important cases, in which the two victims who were the wife and housemaid of the accused, were identified with the help of skeletal remains through the superimposition of photographs. The technique proved to be effective in the distinction and identification of the two slain ladies. Since its introduction in this case, the technique has been extensively used. In contemporary times, computers have made the entire process of superimposition much faster; the accuracy of the process has also improved many times and later in India in the *Taretala Murder Case* (near Calcutta Port)[60], where the Supreme Court accepted skull superimposition as admissible evidence under Section 9 of Indian Evidence Act. Today, it is a widely accepted forensic method for identifying skeletal remains.

3.9.1. Procedure of Photographic Skull Superimposition

From the available photograph of the deceased, a negative is first prepared. Using this negative, a quarter-size positive transparency is produced, on which important anatomical landmarks of the face are marked. This transparency is then placed on the ground glass of a camera, and the

[59] Rex v. Buck Rexton (1935)
[60] Ram Lochan Ahir v. State of West Bengal 1963 AIR 1074

facial outline along with anatomical reference points is traced.

Next, the recovered skull is mounted on a suitable stand and carefully adjusted so that its position and angle correspond exactly with the facial photograph. The anatomical landmarks on the skull must coincide with those marked on the transparency.

Thereafter, negatives of both the skull and the facial photograph are superimposed. If all anatomical landmarks match accurately, a composite positive photograph is prepared. This superimposed image, showing correspondence of key facial and skeletal features, helps establish the identity of the deceased.

When the original photograph does not contain scale details (such as distance from camera), a life-size enlargement of the head is created. The negative of this life-size head is then superimposed on the life-size negative of the skull. A complete match of anatomical landmarks confirms identity.[61]

This method is particularly useful when only skeletal remains are available, and no other means of identification are possible.

This technique is often criticised on the ground that resizing the skull's negative image to match the facial photograph lacks scientific precision. It may even be possible to fit a single skull to photographs of different individuals. Moreover, the actual life-size dimensions of the face are not accurately reproduced in this method. To ensure greater scientific reliability, both the skull and facial negatives should be independently enlarged to life size and only then superimposed for comparison.

In the revised modern method, the person's face in the photograph is first enlarged to life size. This can be done if objects visible in the photograph such as a shirt, spectacles, chair, or saree are available for measurement. For example, the distance between two shirt buttons in the photograph is measured and compared with the actual shirt to calculate the correct enlargement needed for a life-size image. Care must be taken to use only straight-line measurements.

Once the life-size facial image is prepared on diapositive film, the skull is placed on a stand and adjusted to match the same angle and position as the face in the photograph (straight, tilted,

[61] Sumiti Ahuja, Importance of Forensic Facial Reconstruction in Crime Investigation in India, DJCL (Vol. 5), 2023

turned, etc.). The skull is then photographed with a scale to obtain another life-size image.

Both life-size images (face and skull) are placed one over the other and viewed using a light box. After proper alignment, they are fixed together, and a final print is made. This superimposed image is then examined for matching features to help establish identity.

Photographic superimposition cannot conclusively establish identity and is mainly corroborative. Its accuracy depends on photo quality, correct life-size scaling, and expert interpretation, and a skull may sometimes match more than one photograph.

3.10. Voice Print Analysis

Criminals and terrorists frequently use telephone communications for threats, ransom demands, and extortion, while anti-corruption agencies use recorded conversations to trap corrupt officials. In such cases, identifying the speaker becomes crucial for investigation and prosecution. Indian courts have accepted tape-recorded voices as admissible evidence, provided proper recognition is established.[62]

Earlier, voice identification relied only on aural (listening-based) recognition. With advances in electronics, acoustics, and computer technology, scientific voice analysis became possible through spectrographic methods. In the 1960s, Dr. Lawrence Kersta developed the Voiceprint Spectrograph, establishing voice spectrograms as a reliable tool for speaker identification. Today, most forensic laboratories use a combination of aural and visual spectrographic examination, subject to strict testing standards.

The technique is based on the principle that vocal characteristics are influenced by heredity, age, sex, and environmental factors, making each voice practically unique. Identification involves recording the unknown voice, collecting a sample from the suspect using similar speech content, and generating spectrograms for both. Experts then visually compare frequency, amplitude, and timing patterns to determine similarity or dissimilarity.[63]

Although effective, voice print analysis is a complex process that depends heavily on recording quality and examiner expertise and is therefore generally used as corroborative forensic

[62] B.R. Sharma, *Forensic Science in Criminal Investigation and Trials* (5th edn, Universal Law Publishing 2019) 312–318
[63] Upendra Singh Jandu, *Forensic Science in Criminal Justice System* (LexisNexis 2018) 241–246

evidence rather than standalone proof.[64]

Voice recordings and voice print analysis are admissible as expert evidence under Section 45 of the Indian Evidence Act, 1872 (now Section 39, Bharatiya Sakshya Adhiniyam, 2023), subject to proof of authenticity and speaker identification. In *R.M. Malkani v. State of Maharashtra*,[65] the Supreme Court allowed tape-recorded evidence with proper safeguards. *Ram Singh v. Col. Ram Singh*[66] laid down conditions regarding clarity and absence of tampering. In *Ritesh Sinha v. State of U.P.*,[67] the Court held that compelling voice samples does not violate Article 20(3). Voice print evidence is treated as corroborative, not conclusive proof.

3.11. Cyber Forensics

Cyber forensics, also known as digital forensics, is a specialised branch of forensic science concerned with the identification, preservation, analysis and reconstruction of digital evidence obtained from computers, networks, storage devices and related electronic peripherals. Its primary objective is to uncover cyber offences and assist in the effective administration of criminal justice. A cybercrime investigator must possess professional knowledge of computer systems, programming language, operating systems, and network architecture. Equally important is an understanding of legal procedures, since the seizure, preservation and examination of digital evidence must strictly comply with statutory requirements to ensure admissibility in court.

Digital evidence in cybercrime cases may exist in several forms, including computer memory, hard drives, removable storage media, cloud servers, emails, log files and printed records. Investigators commonly employ techniques such as forensic imaging of storage devices, recovery of deleted files, examination of slack and free space, analysis of system logs, and extraction of metadata. Special care is taken to maintain the integrity of evidence through proper documentation and chain of custody, as even minor alterations may compromise its evidentiary value. In network-based crimes, evidence is often transient and geographically dispersed, making identification of offenders more complex. However, technological tools

[64] B.R. Sharma, *Forensic Science in Criminal Investigation and Trials* (5th edn, Universal Law Publishing 2019) 320
[65] R.M. Malkani v. State of Maharashtra (1973) 1 SCC 471
[66] Ram Singh v. Col. Ram Singh AIR 1986 SC 3
[67] Ritesh Sinha v. State of U.P. (2019) 8 SCC 1

such as Internet Protocol (IP) address tracing, domain name analysis, and server log examination enable investigators to locate suspects and reconstruct digital activity trails.

Modern cyber forensics also addresses crimes involving hacking, identity theft, financial fraud, ransomware, online harassment and data breaches. Investigators increasingly rely on advanced software tools, artificial intelligence, and cross-border cooperation to track digital footprints. The availability of IP addresses, timestamps, MAC addresses and user authentication records plays a crucial role in attributing cyber activities to specific individuals or devices.[68]

In India, cyber-forensic evidence and digital records are admissible in criminal proceedings if properly authenticated and collected in compliance with law. The Supreme Court in *Anvar P.V. v. P.K. Basheer*[69] held that electronic records must be supported by a valid 65B certificate under the Indian Evidence Act to prove authenticity, and this requirement was reaffirmed in *Arjun Panditrao Khotkar v. Kailash Kushanrao Gorantyal*[70] as mandatory for admissibility unless the original device is produced in court. Earlier decisions like *Navjot Sandhu*[71] had recognised electronic evidence but were overruled on this procedural point. The Court in *Siddhartha Vashisht v. State of NCT of Delhi*[72] clarified that the chain of custody and integrity of digital evidence must be maintained for it to be reliable, emphasising proper handling and documentation. In *State v. Mohd. Afzal & Others*[73] and *State of Maharashtra v. Bharat Shantilal Shah*[74], courts held that computer-generated records such as call logs, SMS, and text messages are admissible if certified under Section 65B (Section 63 of BSA). Additionally, in cases involving electronic evidence from mobile phones or cloud storage, courts treat such material as expert evidence requiring strict procedural adherence to ensure reliability (including chain of custody and expert testimony where required). These decisions collectively establish that cyber-forensic reports, when lawfully obtained, electronically certified, and transparently documented, are admissible in Indian courts, though they must be corroborated and tested for integrity before being relied upon for conviction.

[68] Prashant Saurabh And Amrit Jay Kumar Roy, Role of Cyber Forensics in Investigation of Cyber Crimes, International Journal of Law Management & Humanities, Vol 4, Issue 3
[69] Anvar P.V. v. P.K. Basheer (2014) 10 SCC 473
[70] Arjun Panditrao Khotkar v. Kailash Kushanrao Gorantyal (2020) 7 SCC 1
[71] State (NCT of Delhi) v. Navjot Sandhu (2005) 11 SCC 600
[72] Sidhartha Vashisht alias Manu Sharma v. State (NCT of Delhi) (2010) 6 SCC 1
[73] State v. Mohd. Afzal & Others 107 (2003) DLT 385
[74] State of Maharashtra v. Bharat Shantilal Shah (2008) 13 SCC 5

3.12. Forensic Odontology

Identification of dead bodies becomes extremely difficult in mass disasters such as fires, floods, earthquakes, explosions and plane crashes, especially when bodies are burnt, mutilated or highly decomposed. In such cases, teeth provide a reliable means of identification because dental enamel is highly resistant to destruction. Similarly, in crimes like burglary and sexual offences, bite marks on food items or on the victim's body can help identify the offender.

Forensic Odontology is the branch of forensic science that applies dental knowledge for legal purposes. It assists both in criminal identification (such as matching bite marks or identifying victims and offenders) and non-criminal identification (such as identifying disaster victims or unknown bodies). Teeth and dental records like dental charts, X-rays, casts and photographs are compared with ante-mortem records to establish identity.

Forensic odontology is especially useful when other methods fail. Bite marks left by offenders on victims, by victims on assailants (in self-defence), or on food during burglary can be recorded through photography and casting for comparison. Dental examination can also help estimate age, identify social status from dental treatment, determine habits like smoking or tobacco chewing, and sometimes even indicate profession based on tooth wear. Dentures may also help identify the victim's country of origin, as their materials vary across regions.

Thus, forensic odontology plays a vital role in criminal investigation and disaster victim identification by providing scientific and durable evidence through dental characteristics.[75]

The Supreme Court has recognised forensic odontology as corroborative scientific evidence in cases such as *Ram Narain Singh v. State of Punjab*[76], *Ravinder Singh v. State of Haryana*,[77] and *Mukesh v. State (NCT of Delhi)*[78], where dental injuries and bite marks helped in identification and linking accused to crime.

Identification depends on availability of ante-mortem dental records. Bite-mark analysis is subjective due to skin distortion and examiner variation. Dental evidence may be destroyed in extreme conditions like fire or decomposition. Similar dental patterns can also lead to possible

[75] Sumiti Ahuja, Importance of Forensic Facial Reconstruction in Crime Investigation in India, DJCL (Vol. 5), 2023
[76] Ram Narain Singh v. State of Punjab (1975) 4 SCC 497
[77] Ravinder Singh v. State of Haryana (1975) 3 SCC 742
[78] Mukesh v. State (NCT of Delhi) (2017) 6 SCC 1 (Nirbhaya Case)

errors in identification.

4. Critical Appraisal

Despite significant progress, forensic science in India still faces many serious challenges. Poor infrastructure, shortage of trained forensic experts, and lack of adequate funding limit its effectiveness. At the same time, criminals are becoming more sophisticated, especially with the rapid rise of cybercrime, making it essential for forensic methods to continuously evolve.

Many forensic laboratories lack modern equipment and proper facilities, which affects the accuracy of investigations. There is also a serious shortage of skilled professionals, leading to delays in criminal trials. Investigating officers often do not receive sufficient training in collecting, preserving, and handling forensic evidence, resulting in contamination or loss of crucial material.

The Supreme Court in *Dharam Deo Yadav v. State of Uttar Pradesh*[79] emphasised that forensic evidence plays a vital role in serious crimes, and flawed forensic practices can lead to wrongful convictions. This highlights the urgent need to improve both scientific capacity and investigative skills.

Cybercrime further complicates forensic work, as digital criminals constantly change their techniques. To address this, India must invest in modern technology, strengthen training programmes, and encourage innovation in forensic science.

Most forensic laboratories in India function under police or government control, which sometimes raises doubts about their independence. Courts also treat forensic reports cautiously because they often provide probabilistic conclusions rather than definite proof. Additional problems include lack of research, weak ethical standards, limited databases, and absence of reliable error-rate data.

Internationally recognised principles such as the *Daubert* standards[80] stress that scientific evidence must be tested, peer-reviewed, widely accepted, and supported by known error rates. Indian courts similarly scrutinise expert testimony through examination and cross-examination. To meet these expectations, forensic professionals must undergo rigorous training and regular

[79] Dharam Deo Yadav v. State of Uttar Pradesh (2014) 5 SCC 509
[80] Daubert v. Merrell Dow Pharmaceuticals, Inc. 509 U.S. 579 (1993)

skill upgrades.

Overall, improving forensic science in India requires a holistic approach, better infrastructure, stronger training, independent laboratories, scientific audits, and continuous legal oversight, to ensure reliable evidence and faster, fairer justice.

5. Conclusion

Recent advancements in forensic science have profoundly reshaped the landscape of criminal adjudication by strengthening the accuracy and objectivity of fact-finding processes. Techniques such as DNA profiling, fingerprint analysis, forensic odontology, voice print examination, photographic superimposition, and cyber forensics now play a central role in linking suspects to crime scenes, identifying victims, and reconstructing criminal events. These scientific tools, when properly collected and interpreted, enhance investigative efficiency and provide courts with highly probative evidence, thereby reducing reliance on purely testimonial proof.

At the same time, the evolution of forensic science has revealed important constitutional and ethical concerns. While objective methods like DNA analysis and biometrics offer high reliability, intrusive techniques such as narco-analysis, brain mapping, and polygraph testing raise serious questions relating to personal liberty, mental autonomy, and the right against self-incrimination. The Supreme Court's ruling in *Selvi v. State of Karnataka*[81] marks a decisive moment in Indian jurisprudence by affirming that involuntary administration of such techniques violates Articles 20(3) and 21 of the Constitution. This judgment reflects India's rights-oriented approach, ensuring that scientific progress does not come at the cost of constitutional morality.

The enactment of the Bharatiya Sakshya Adhiniyam, 2023 represents a significant step toward modernising evidentiary law by expressly accommodating electronic records, digital evidence, and contemporary forensic practices. However, the new legislation does not fundamentally alter the traditional judicial philosophy governing expert evidence. Courts continue to insist on corroboration, methodological reliability, and careful scrutiny of expert testimony. Forensic evidence remains supportive rather than conclusive, reinforcing the principle that scientific

[81] Selvi v. State of Karnataka AIR 2010 S.C. 1974

inputs must complement, not replace, judicial reasoning.

Despite these legal advancements, practical challenges persist. India continues to struggle with inadequate forensic infrastructure, shortage of trained professionals, procedural lapses in evidence collection, and delays in laboratory analysis. The growing complexity of cybercrime further strains existing capacities. Moreover, concerns regarding the independence of forensic laboratories, lack of standardised protocols, and absence of comprehensive error-rate data risk undermining public confidence in forensic outcomes.

Comparative experience from jurisdictions such as the United Kingdom and the United States demonstrates that scientific utility must always be balanced against privacy and due process guarantees. In this context, India's post-*Selvi* jurisprudence reflects a cautious yet progressive trajectory, embracing technological innovation while maintaining constitutional safeguards.

Ultimately, the future of forensic science in India must be anchored in a robust legal and institutional framework that prioritises fairness, scientific integrity, and human dignity. Legislative reform alone is insufficient. What is equally required is sustained investment in forensic infrastructure, uniform national standards, judicial training in scientific evidence, independent laboratory governance, and continuous capacity-building of investigators and experts. Only through such a holistic approach can forensic science truly serve its intended purpose: not merely securing convictions, but advancing truth, protecting rights, and strengthening public faith in the criminal justice system.

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