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**Review Article**

# Forensic DNA fingerprinting in Indian criminal justice system: Issues and challenges

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## Abstract

Forensic DNA fingerprinting plays a key role by providing scientific evidence that assists investigating officers in solving criminal cases. It is also helpful to judges while determining the accused's guilt during the trial process. However, it has raised serious concerns over wrongful convictions based on faulty forensic evidence. In many cases, courts have convicted several individuals based on faulty forensic evidence and later they were released them from prisons based on further DNA tests. Some of the challenges include limitations of forensic DNA fingerprinting techniques, limited Standard Operating Procedures (SOPs), shortage of infrastructure facilities, and inadequate staff strength. Additionally, gaps in training and coordination between forensic medicine experts and investigative agencies often affect the quality, reliability, credibility of forensic evidence. Further, the recent enactment of the Criminal Procedure (Identification) Act, 2022 has raised complex legal and ethical concerns regarding individual privacy, data security, and the admissibility of DNA evidence in court. This paper aims to explore the legal challenges including validity, reliability, and admissibility of Forensic DNA Profiling techniques in India. It also provides suggestions to enhance the reliability and admissibility of forensic evidence in the court of law.

**Keywords**: Forensic DNA fingerprinting, Wrongful convictions, Faulty forensic evidence, Quality assurance, Forensic medicine, Legal challenges.

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## 1. Introduction

Forensic DNA fingerprinting is an indispensable tool in the field of criminal justice system. It has the ability to match biological samples like blood, hair, saliva, sweat, sputum and other bodily fluids etc., found at a crime scene. The DNA technology has emerged as a transformative tool in the Indian criminal justice system, particularly in cases where traditional investigative methods are inadequate. Its precision and reliability in identifying individuals have significantly enhanced the ability of law enforcement agencies to solve complex crimes, ensure accurate convictions, and exonerate the innocent. Despite these advancements, the integration of forensic DNA fingerprinting into the Indian criminal justice system faces several challenges including scientific limitations, legal complexities surrounding the admissibility of DNA evidence in courts.

Although, Indian judiciary recognised the DNA evidence as valid, there are still significant gaps regarding the sample collection methods, preservation, and analysis. It also deals with unresolved legal and ethical concerns, particularly those related to privacy and data protection which continue to undermine the credibility and effectiveness of the criminal justice system. In addition, other challenges including the lack of uniform standard operating procedures that often leads to inconsistencies in practice. This review explores the current landscape of forensic DNA fingerprinting in India, critically examining the multifaceted challenges that hinder its effective implementation in the criminal justice system. It also proposes potential solutions, such as enactment of a comprehensive legal framework, enhance capacity building, and the establishment of standard operating protocols aligned with international best practices.

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## 2. Forensic DNA Analysis

The human genome comprises two long polynucleotide chains encoded as Deoxyribonucleic Acid (DNA), which encapsulates genetic information through specific sequences of four nucleotide bases: adenine (A), thymine (T), cytosine (C), and guanine (G).[1] These nucleotide bases pair between two antiparallel strands (A-T and C-G) to form the characteristic double helix structure.[2] DNA plays a crucial role in crime detection because every human possesses approximately 0.1% distinct DNA, except monozygotic twins. It is found in bodily substances like skin cells, tissues, blood, saliva, bone, and semen, which can be detected using forensic techniques.

Forensic DNA Fingerprinting is a technique applied to ascertain an individual's identity by examining distinctive patterns in their DNA. This technique is also interchangeably referred to as Forensic DNA Typing or Forensic DNA Profiling. In 1977, Frederick Sanger developed the first-generation sequencing, which is based on the amplification of a DNA template and the use of gel electrophoresis for sequence analysis. This method uses chain-terminating dideoxynucleotides (ddNTPs) during DNA replication to create fragments of varying lengths, which are then separated by capillary electrophoresis to determine the DNA sequence.[3] However, Sanger sequencing has certain limitations such as labor-intensive, time-consuming and expensive for large-scale projects. This sequencing technology provides low throughput that restrict its application in modern high-demand fields such as medicine and large population studies. In view of these limitations, more advanced technologies were developed, offering high throughput and faster processing time.

In the mid-1980s, Sir Alec Jeffrey developed one of the methods of Forensic DNA Typing viz., Restriction Fragment Length Polymorphism (RFLP). In this method, forensic experts use a variety of solvents to break down the DNA into different fragment lengths.[4] When specific sequences of bases occur, these enzymes cut the DNA into a variable number of tandem repeats (VNTRs). These VNTR segments have limitations while determining whether identical band patterns are derived from a single or several persons.[5] In the early 1990s, forensic DNA analysts adopted the Polymerase Chain Reaction–Capillary Electrophoresis (PCR-CE) method, supplanting the Restriction Fragment Length Polymorphism (RFLP) technique. This PCR method amplifies DNA into short tandem repeat (STRs), offering improved sensitivity, rapid results, and enhanced genotyping accuracy. However, the high sensitivity of PCR method poses certain limitations, particularly when analyzing low-quality or degraded DNA samples.[6]

Some of the challenges associated with the PCR-CE method include low-template DNA (LTDNA), contamination, DNA mixtures etc. Generally, the PCR-CE method provides reliable results in amplifying genetic material. However, even slight amplification errors in low-template DNA (LTDNA) can significantly affect the accuracy of the results.[7] Also, the PCR method is highly susceptible to contamination; where even trace amounts of foreign DNA can result in misinterpretations and potentially erroneous conclusions. Additionally, DNA mixtures consisiting DNA of several individuals pose interpretation challenges, as conventional methods often struggle to resolve overlapping genetic profiles with precision. Beyond these challenges, the PCR-CE method involves substantial operational costs and time. These limitations have hindered the effectiveness of PCR-CE method in handling complex genomic analyses and underscores the need for more robust, sensitive, and cost-efficient techniques in DNA analysis.[8]

Furthermore, forensic DNA analysts have increasingly adopted Y-chromosome Short Tandem Repeat (Y-STR) analysis in criminal investigations. This Y-STR profiling is a specialized forensic DNA technique that targets specific repeating sequences on the Y chromosome, which is passed exclusively through the paternal line. This method is particularly useful in determining paternity, genealogical DNA testing, and sexual assault cases.[9] It enables the selective amplification and identification of male-specific genetic material from complex biological mixtures. However, it has significant limitations such as identical Y-STR profile i.e., all males within the same paternal lineage share identical Y-STR profiles, as the Y chromosome is passed virtually unchanged from father to son. Consequently, Y-STR analysis cannot distinguish among male relatives, significantly reducing its discriminatory power compared to autosomal STR analysis. Additionally, the rarity of mutations in Y-STR loci means that different individuals from the same male lineage may remain indistinguishable for many generations. This limitation makes inconclusive DNA evidence in identifying individual perpetrators, and it must be interpreted with caution, especially in populations or communities with limited genetic diversity.[10]

## 3. DNA Sequencing Technology

The Sanger sequencing method laid a pivotal foundation for scientific advancements in forensic DNA analysis, paving the way for the development of sophisticated high-throughput sequencing (HTS) technologies. Forensic DNA typing has witnessed a remarkable evolution transitioning from gel electrophoresis, capillary electrophoresis to massively parallel sequencing (MPS). This technique is also known as Next Generation Sequencing (NGS) or High Throughput Sequencing (HTS), represents a cutting-edge approach in DNA analysis. This technology is used when conventional methods falls short in providing reliable or comprehensive results, especially in cases involving degraded DNA samples. In DNA profiling, next-generation sequencing (NGS) allows simultaneous analysis of multiple STR loci and provides higher resolution and discriminatory capability. It can handle complex DNA mixtures more effectively and also provides more information regarding DNA samples than traditional PCR-CE methods.[11]

Furthermore, next-generation sequencing is also applied to mitochondrial DNA sequencing (mtDNA) for improved resolution and sensitivity. Forensic DNA Analysts use mitochondrial DNA sequencing for small quantities or degraded DNA samples. MPS technology, along with advanced bioinformatics algorithms, decodes complex DNA mixtures. This technique is useful for deconvoluting mixture samples and accurately identifying the individuals.[12] MPS technology and two other technologies may also be applied: sequencing-by-synthesis from Illumina and semiconductor-based ion torrent sequencing from Thermo Fisher.[13] It also significantly improved the precision of DNA results, leading to the extraction of greater information from DNA samples. Moreover, these technological advancements facilitate forensic experts to choose the most suitable technique for DNA samples depending on sample size and quality. Consequently, DNA typing was pivotal in cracking criminal cases and exonerating innocent people.

## 4. Recent Developments in Forensic DNA Analysis

The third-generation sequencing (TGS) produces long-read DNA sequences, surpassing the lengths of short-read sequencing methods like Next-Generation Sequencing (NGS).[14] It enables the sequencing of single DNA molecules, resulting in long read lengths and high accuracy. Such long-read sequencing has been very helpful in improving genome composition. The TGS technique has the ability to sequence DNA or RNA without any previous amplification. It is particularly significant as it ameliorates the biases introduced during the library preparation of the sample.[15] The TGS technologies like nanopore sequencing, long-read isoform sequencing (Iso-seq), single-molecule real-time (SMRT) of Pacific Biosciences represent cutting-edge approaches in DNA sequencing methods· These technologies use zero-mode waveguides (ZMWs) that emits sequential bursts of lights to observe DNA polymerase activity in real-time as it incorporates fluorescently labeled nucleotides. It enables sequencing of single DNA molecules, resulting in long read lengths and high accuracy. Such long-read sequencing has been very helpful in improving genome composition.

The TGS technology addresses several limitations associated with NGS technology. It (TGS) provides enhanced sequencing capability, yielding superior read depth and improved accuracy. The fundamental constraint of NGS technology is its reliance on short-read sequencing, which necessitates specialized bioinformatics tools and extensive post-processing pipelines. These requirements substantially increase computational demands and prolong data analysis timelines. In contrast, TGS technology produces ‘long reads’, significantly improving the quality of genome assembly and the analysis of genome structures. Moreover, the TGS technology leads to less bias and more homogenous genome coverage due to absence of PCR amplification.[16] However, TGS technology exhibits certain limitations including the suboptimal performance in homopolymer sequences, low throughput and high costs.[17] In future, these technologies must prioritize enhancing sequencing accuracy, developing portable sequencing devices, and reducing costs to achieve rapid results.

## 5. Discussion

### *5.1. DNA profiling in India: Current perspectives*

Forensic DNA fingerprinting has significantly transformed the legal landscape in India. DNA evidence is crucial in various crimes, including rape, sexual assault, murder, etc., for investigation and trial purposes. In Kunhiraman v. Manoj,[18] the Kerala High Court used DNA evidence to resolve paternity disputes.[19] Consequently, the Indian judiciary used DNA profiling as a significant tool in criminal cases, which resolved several high-profile and cold cases. However, Indian courts considered DNA evidence as corroborative evidence only. In Hemudan Nanbha Gadhvi v. The State of Gujarat,[20] the Apex Court convicted the rape accused solely relying on medical evidence, even though the victim turned hostile. In Prithviraj Jayantibhai Vanol v. Dinesh Dayabhai Vala and Others,[21] the Supreme Court held that medical evidence prevails over ocular evidence. If ocular testimony is implausible, if it is ruled out as a possibility of being true.

Although DNA fingerprinting holds immense evidentiary value in the Indian criminal justice system, its implementation is fraught with several challenges. One of the major bottlenecks is the lack of comprehensive legislation. In the meantime, Indian courts have recognized DNA evidence as valid, however, its admissibility often depends on judicial discretion due to this legal vacuum. This legislative gap also raises constitutional concerns, particularly regarding potential violations of individuals' right to privacy. Also, the India’s overburdened judiciary struggles with integrating DNA evidence effectively. These problems were exacerbated by systemic and infrastructural shortcomings including inadequate forensic facilities, high costs, procedural delays, and non-standardized processes.

### *5.2. Laws relating to forensic DNA profiling*

Forensic experts shall collect DNA evidence with utmost care and caution to prevent sample contamination. If the court finds any inconsistency with the DNA results, the defense counsel will raise serious doubts regarding the reliability of the samples. Such evidence is inadmissible due to its unreliability and failure to meet the necessary standards to ensure a fair and just trial. Moreover, the Indian legal system lacks specific legislation relating to forensic DNA profiling like collection, storage, and analysis. Article 51A (h) of the Constitution of India (COI) states that "every citizen has a fundamental duty to develop scientific temper, humanism and the spirit of inquiry and reform." Article 51A (j) COI promotes "every citizen has fundamental duty to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement." However, criminal laws show a lack of legislative modernization relating to scientific advancements, raising concerns about potential loops in collecting forensic evidence.

When a police officer receives information regarding the commission of a cognizable offence which is punishable with imprisonment of seven years or more. Such police officers shall ensure that the forensic experts visit the crime scene to collect forensic evidence. This process shall be videographed through mobile or any other electronic devices.[22] If a forensic facility is unavailable for any offense, the State Government shall notify utilization of facilities of another state until the facility is developed or made within the state. During the investigation, when the police have reason to believe that the medical examination will provide evidence relating to the offense, they may request the registered medical practitioner (RMP) to conduct a medical examination of the accused.[23] This medical examination includes an examination of various bodily fluids, including blood, sweat, blood stains, swab samples, semen, hair, fingernails, and sputum etc., through the application of scientific methods, including DNA profiling and other necessary tests.[24]

Additionally, the Indian Government put forth the DNA Technology (Use and Application) Regulation Bill, 2019 to provide the regulatory framework for using and applying DNA technology within the criminal justice system. In Parliament, the DNA Technology Bill has been introduced multiple times, but the opposition raised serious concerns about potential threats to individuals' privacy, the accuracy of DNA technology, and the possibility of abuse. In 2023, the Government withdrawn the DNA Technology (Use and Application) Regulation Bill citing that the provisions were covered under the Criminal Procedure (Identification) Act (CPIA), 2022. The CPIA aims to collect measurements from convicted and other persons for identification and investigation purposes.

According to section 3 of the CPIA, the State can take measurements of the accused or arrested persons. Such measurements include fingerprints, photographs, iris and retina scans, samples such as blood, semen, hair, swab, behaviourial attributes like signatures etc.[25] The National Crime Records Bureau (NCRB) collects and stores these measurements in digital or electronic form for 75 years from the date of collection of such measurements to prevent, detect, investigate, and prosecute offences under any law.[26] If the person is released without trial, discharged or acquitted by the court, all records of measurements so taken shall be destroyed from records duly obtaining the court orders. The court or Magistrate may retain such measurements duly recording the reasons in writing.

Furthermore, when the police officer or prison officer taking these measurements, if the person resists or refuses to allow taking of such measurements, he shall be deemed to be committed an offence under section 186 of Indian Penal Code (now corresponding to Section 221 of Bharatiya Nyaya Sanhita, 2023).[27] Although, the accused haven't committed any such offence, but he had resisted or refused to allow taking of the measurements amounts to an offence under section 6 of the CPIA. According to the section 221 BNS, 2023, when a person voluntarily obstructs any public servant in the discharge of his public functions, he shall be punished with imprisonment for a term which may extend to three months, or with fine which may extend to five hundred rupees, or with both.

Many activists raised concerns that this law may infringe various rights guaranteed under the Constitution of India.[28] Further, the Criminal Procedure (Identification) Act, 2022 has to pass the test of proportionality to be declared as constitutionally valid. This test of proportionality has been laid down in Puttaswamy's case. In Justice K.S. Puttaswamy (Retd.) v. Union of India,[29] the Supreme Court of India held that "the test of proportionality, i.e., (a) existence of a law; (b) must serve a legitimate State aim; and (c) proportionality. The test of proportionality shall fulfill the following conditions, namely (i) a measure restricting a right must serve a legitimate goal (legitimate goal stage), (ii) such measure must be a suitable means of furthering this goal (suitability or rational connection stage), (iii) there must not be any less restrictive but equally effective alternative (necessity stage) and (iv) measure must not have a disproportionate impact on the right-holder (balancing stage)." This Act aims to collect measurements from convicts for investigation purposes. However, this act fails to satisfy the other three conditions, namely the suitability stage, necessity stage, and balancing stage.

When Government scientific experts examine and analyze forensic evidence and submit reports, it may be used as evidence in inquiries, trials, or other criminal proceedings. The courts may summon and examine these experts regarding the subject matter of reports. If an expert is unable to attend court personally, he may depute any responsible officer who is conversant with the facts of the case to appear before the court. This provision applies to various government scientific experts, including Chemical Examiners or Assistant Chemical Examiners; the Director of Finger Print Bureau; the Director of Haffkeine Institute, Bombay; the Chief of Controller of Explosives; the Director, Deputy Director, or Assistant Director of Central Forensic Science Laboratory (CFSL) or a State Forensic Science Laboratory (SFSL); serologists, and any other designated scientific experts by the Central or State Governments.[30] Additionally, the Court can take experts' opinions to form an opinion on foreign law, science, art, any other field, or in question as to identity of handwriting or finger impressions are relevant.[31] Furthermore, courts can compel individuals to furnish fingerprints, handwriting samples, or signatures for the purpose of comparison.[32]

### *5.3. Reliability of DNA profiling test*

DNA profiling tests are crucial in providing scientific evidence in criminal cases. Such evidence not only aids police officers in solving criminal cases but also assists courts in determining the accused's guilt during trials. However, forensic DNA evidence raised serious concerns regarding wrongful convictions based on faulty forensic evidence. It is reported that many individuals were convicted relying on faulty forensic evidence and they were released from prisons on subsequent DNA tests. These wrongful convictions may result from insufficient forensic training for forensic experts and police officers, limited SOPs and accreditation of forensic science laboratories, and infrastructural limitations that impact the quality, reliability, credibility of forensic evidence. Additionally, shifting crime patterns and scientific advancements pose new challenges to forensic science. Thus, there is an urgent need for a comprehensive analysis of forensic science in India.

In Dharam Deo Yadav v. State of Uttar Pradesh,[33] the Supreme Court held that the DNA Profiling test is valid and reliable; however, DNA results depend on quality control and quality procedures in the laboratory. In Rahul v. The State of Delhi, Ministry of Home Affairs and Another,[34] the Supreme Court held that all the accused were acquitted despite the DNA match and other findings on the grounds that neither the Trial Court nor the High Court examined the underlying basis of the conclusions in the DNA reports and whether the expert had reliably applied the techniques. All DNA reports are highly vulnerable without such evidence, especially when the sample collection and storage are not free from suspicion.

In Manoj v. The State of Madhya Pradesh,[35] the Supreme Court held that the expert explained the DNA analysis, but he did not mention the random occurrence ratio or random match probability (RMP), i.e., the probability of the accused's samples matching with those samples allegedly found at the crime scene. Further, the Court held that the reference sample was collected from an open area, and there was likelihood for contamination. Although the genuineness of its recovery is acknowledged, these samples carried some degree of probability. Thus, the Supreme Court held that this DNA report cannot have a clinching or high degree of probative value.

### *5.4. Admissibility of forensic DNA evidence*

Section 141 of Bharatiya Sakshya Adhiniyam, 2023 empowers the judges to decide as to the admissibility of evidence. The Judge may seek the proposing party regarding the manner in which the alleged fact is relevant and, if proven, would be a relevant fact. Indian courts have to evaluate scientific methods to ascertain the admissibility of scientific evidence based on the validity and reliability of forensic tests. Firstly, the courts assess the "foundational validity" of forensic tests based on the precision, reliability, and reproducibility. Secondly, the courts examine "validity as applied," considering the expert's capability to apply the techniques and the accuracy of the results.[36] Further, the trial courts' judges experience legal challenges while evaluating scientific evidence due to a lack of standards for the admissibility of scientific evidence in India.

## 6. Conclusion

Forensic DNA fingerprinting has had significant advancements that have revolutionized the field of forensic science. However, India has only 63 operational sites for next-generation sequencing (NGS) technologies distributed across 24 Indian states and three Union Territories. It has no operational sites for third-generation sequencing (TGS) technologies. This limited infrastructure poses significant constraints on the application of cutting-edge forensic techniques within the country. Additionally, Indian trial courts' judges face challenges in evaluating multifarious aspects of scientific evidence due to the lack of standards to determine the admissibility of experts' testimony. It also resulted in the lack of uniformity in the admissibility of the expert's evidence. Therefore, it is imperative to incorporate legal standards for admissibility of scientific evidence to enhance the evidentiary value of forensic evidence.

## 7. Source of Funding

None.

## 8. Conflict of Interest

None.

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