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DNA EVIDENCE IN CRIMINAL INVESTIGATIONS: RELIABILITY CHALLENGES AND JUDICIAL TRENDS

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ABSTRACT

Deoxyribonucleic acid (DNA) evidence has fundamentally transformed the landscape of criminal investigations and adjudication since its first forensic application in the landmark case of *R v. Colin Pitchfork* in 1986. Over the past four decades, DNA profiling has evolved from a rudimentary serological tool to a sophisticated forensic instrument capable of analysing degraded, mixed, or microscopic biological samples with extraordinary precision. This paper critically examines the dual dimensions of DNA evidence in criminal proceedings: its scientific reliability and the concomitant judicial challenges that arise from its deployment in courts of law. While DNA evidence boasts a theoretical error rate of approximately one in several billion in standard cases, its practical reliability is significantly mediated by factors such as laboratory contamination, improper chain of custody, misinterpretation of mixed DNA profiles, probabilistic genotyping controversies, and systemic biases in forensic laboratories. The paper further analyses the evolving judicial trends in India, the United States, and the United Kingdom with respect to the admissibility, evidentiary weight, and interpretive standards applied to DNA evidence. The paper explores landmark judicial pronouncements including *Daubert v. Merrell Dow Pharmaceuticals*, *Frye v. United States*, and Indian Supreme Court decisions to illustrate how courts have grappled with the intersection of science and law. The authors argue that while DNA evidence represents the gold standard of forensic science, uncritical judicial deference to such evidence, in the absence of robust procedural safeguards, poses substantial risks to the principles of fair trial and the presumption of innocence.

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Comprehensive legislative reform, judicial training, and standardisation of forensic protocols are urgently recommended to ensure the just and reliable use of DNA evidence in criminal justice systems.

Keywords: *DNA Evidence, Forensic Science, Criminal Investigations, Judicial Trends, Admissibility, Reliability, Wrongful Convictions, Probabilistic Genotyping, India, Forensic Legislation.*

I. INTRODUCTION

The introduction of DNA profiling into the arsenal of forensic science constitutes one of the most consequential developments in the history of criminal justice. The discovery of the polymerase chain reaction (PCR) technique and subsequent advances in short tandem repeat (STR) analysis have enabled forensic scientists to generate highly individualised genetic profiles from trace biological material such as blood, saliva, hair follicles, semen, and skin cells.[1] These profiles, often characterised by statistical probabilities exceeding one in a trillion, have become the paradigmatic form of objective evidence in courtrooms across the globe.

In India, the admissibility and use of DNA evidence in criminal proceedings have been governed by a patchwork of statutory provisions and judicial interpretations. The Indian Evidence Act, 1872, the Code of Criminal Procedure, 1973, and the recently enacted Bharatiya Nagarik Suraksha Sanhita, 2023, collectively provide the procedural framework, while the DNA Technology (Use and Application) Regulation Bill, 2019, represents a legislative attempt to standardise and regulate DNA profiling. However, as of the time of writing, comprehensive standalone DNA legislation remains absent from the Indian legal landscape, creating significant lacunae in the regulation of forensic evidence.[2]

The reliability of DNA evidence, while considerable, is not absolute. The high-profile cases of wrongful convictions overturned by post-conviction DNA testing in the United States, documented extensively by the Innocence Project, have exposed systemic vulnerabilities in the forensic process.[3] From laboratory cross-contamination and mishandling of biological samples to the misinterpretation of complex mixed DNA profiles and the growing controversy

[1]Kary Mullis, 'The Unusual Origin of the Polymerase Chain Reaction' (1990) 262 Scientific American 56; Peter Gill, Alec Jeffreys & David Werrett, 'Forensic Application of DNA Fingerprinting' (1985) 318 Nature 577.
[2]Centre for Child and the Law, National Law School of India University, 'The DNA Technology (Use and Application) Regulation Bill, 2019: A Critical Analysis' (2019) NLSIU Working Paper.
[3]Innocence Project, 'DNA Exonerations in the United States (1989–2020)' <https://innocenceproject.org/dna-exonerations-in-the-united-states> accessed 1 February 2025.

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surrounding software-driven probabilistic genotyping, the reliability of DNA evidence in practice diverges substantially from its theoretical perfection. These vulnerabilities are compounded by the phenomenon of the 'CSI effect,' whereby juries and judges attribute near-infallible authority to forensic science testimony, often without adequate scrutiny of the underlying methodology.

This paper proceeds in six substantive sections. Following this introduction, Section II presents a review of the existing scholarly literature on DNA evidence, reliability concerns, and judicial responses. Section III examines the legal framework governing DNA evidence in India, the United States, and the United Kingdom. Section IV undertakes a detailed analysis of landmark case laws that have shaped judicial trends in the assessment of DNA evidence. Section V identifies the key challenges to DNA evidence and offers recommendations for reform. Section VI concludes the paper with a synthesis of the principal findings and broader reflections on the future of DNA evidence in criminal justice.

The methodology adopted in this paper is primarily doctrinal and comparative. The authors have analysed primary legal sources including statutes, judicial decisions, and official reports, alongside secondary literature comprising academic articles, forensic science studies, and policy documents. The comparative dimension draws upon the legal frameworks and judicial experiences of India, the United States, and the United Kingdom to derive broader lessons applicable to the development of DNA regulation in India.

II. LITERATURE REVIEW

The intersection of genetics and criminal law has generated an extensive and multidisciplinary body of scholarship. Alec Jeffreys, whose pioneering work at the University of Leicester in the mid-1980s led to the discovery of genetic fingerprinting, first articulated the forensic potential of DNA polymorphisms in 1985.[4] Jeffreys and his colleagues demonstrated that individual variation in the repetitive sequences of DNA, particularly variable number of tandem repeats (VNTRs), could be exploited to generate a unique genetic profile for each individual, analogous to a biological fingerprint. This seminal contribution laid the scientific groundwork for the forensic use of DNA.

The legal scholarship on DNA evidence has evolved in tandem with advances in forensic science. In the United States, the National Research Council's landmark report, *Strengthening Forensic Science in the United States: A Path Forward* (2009), offered a devastating critique

[4]Alec Jeffreys, Victoria Wilson & Swee Lay Thein, 'Hypervariable Minisatellite Regions in Human DNA' (1985) 314 Nature 67.

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of the broader forensic science enterprise, finding that most forensic disciplines, with the partial exception of nuclear DNA analysis, lacked a sufficient scientific foundation to reliably link crime scene evidence to individual suspects.[5] The report highlighted the absence of mandatory accreditation, standardised protocols, and rigorous quality assurance mechanisms across forensic laboratories, and called for systemic reform.

Jay Aronson's monograph *Genetic Witness: Science, Law, and Controversy in the Making of DNA Profiling* (2007) provides a detailed historical and sociological account of the emergence of DNA evidence as a legal category.[6] Aronson traces the contentious early battles over the admissibility of DNA evidence in American courts, noting how the initial optimism of forensic scientists was tempered by serious concerns about laboratory quality, statistical methodology, and the potential for racial bias in DNA databases.

In the Indian context, scholarly attention to DNA evidence has been comparatively limited but is growing. Professor K.I. Vibhute's analysis of scientific evidence under Indian evidentiary law highlights the tensions between the traditional common law preference for oral testimony and the growing evidentiary significance of scientific and expert evidence.[7] Similarly, scholars such as Sanjay Jain and Usha Ramanathan have examined the civil liberties implications of DNA databasing, arguing that the broad scope of the proposed DNA Technology Regulation Bill poses significant risks to privacy and the presumption of innocence.

The reliability of DNA evidence as a forensic tool has been subjected to considerable critical scrutiny. William Thompson, Simon Ford, and Travis Doom have documented the phenomenon of 'DNA evidence errors,' including cases of sample transposition, contamination, and database search coincidences, in which random matches occur by chance in large databases.[8] The 'prosecutor's fallacy,' a form of statistical reasoning error in which the probability of a random match is equated with the probability of innocence, has been identified as a recurring problem in the presentation of DNA statistics to juries.

The debate over probabilistic genotyping software, including tools such as TrueAllele and STRmix, has generated a vigorous scholarly controversy.[9] Critics, including Erin Murphy of New York University School of Law, have argued that the opacity and proprietary nature of

[5]National Research Council, Strengthening Forensic Science in the United States: A Path Forward (National Academies Press 2009) 87.
[6]Jay Aronson, Genetic Witness: Science, Law, and Controversy in the Making of DNA Profiling (Rutgers University Press 2007) 14.
[7]K.I. Vibhute, 'Scientific Evidence under Indian Law: Emerging Judicial Responses' (2011) 53 Journal of the Indian Law Institute 199.
[8]William Thompson, Simon Ford & Travis Doom, 'Evaluating Forensic DNA Evidence' (2003) 57 The Champion 16.
[9]Erin Murphy, Inside the Cell: The Dark Side of Forensic DNA (Nation Books 2015) 231.

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such software undermines the ability of defence counsel to mount an effective challenge to the evidence, raising serious due process concerns. Murphy's authoritative text, *Inside the Cell: The Dark Side of Forensic DNA* (2015), remains the definitive critical assessment of the legal and ethical dimensions of forensic DNA evidence in the United States.

In the United Kingdom, the House of Commons Science and Technology Committee's report on *Forensic Science* (2019) expressed concern about the fragmented and market-driven nature of forensic service provision following the closure of the Forensic Science Service in 2012.[10] The report warned that quality standards had deteriorated and that the courts were ill-equipped to evaluate the reliability of forensic science evidence. The report echoed broader scholarly concerns about the lack of an epistemological foundation for the use of forensic science in adversarial legal proceedings.

Indian courts have increasingly had to grapple with the admissibility and weight of DNA evidence in a diverse range of cases, from paternity disputes and rape prosecutions to terrorist investigations and large-scale fraud. The Supreme Court of India's decisions in *Pantangi Balarama Venkata Ganesh v. State of Andhra Pradesh* and *Krishan Kumar Malik v. State of Haryana* have begun to articulate standards for the judicial evaluation of DNA evidence, but a comprehensive doctrinal framework remains elusive.[11]

The literature thus reveals a complex picture: DNA evidence is simultaneously the most scientifically robust form of forensic evidence and the most susceptible to systemic vulnerabilities arising from the gap between its theoretical reliability and its practical application in the varied conditions of criminal investigations. The present paper seeks to contribute to this literature by examining these tensions through the lens of comparative legal analysis and Indian judicial experience.

III. LEGAL FRAMEWORK AND ANALYSIS

A. The Scientific Basis of DNA Profiling

Human DNA consists of approximately 3.2 billion base pairs, of which over 99.9 percent are identical across the human species. Forensic DNA analysis focuses on the remaining 0.1 percent, which includes regions of highly variable repetitive sequences known as short tandem repeats (STRs).[12] By analysing the number of repetitions at a set of standardised genetic loci,

[10]House of Commons Science and Technology Committee, Forensic Science (HC 2018–19, 1883) para 4.
[11]Pantangi Balarama Venkata Ganesh v State of Andhra Pradesh (2009) 14 SCC 671; Krishan Kumar Malik v State of Haryana (2011) 7 SCC 130.
[12]John Butler, Forensic DNA Typing: Biology, Technology and Genetics of STR Markers (2nd edn, Academic Press 2005) 22.

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forensic scientists can generate a DNA profile that is, for all practical purposes, unique to each individual (with the exception of identical twins). The Combined DNA Index System (CODIS) in the United States employs a core set of twenty STR loci, while the United Kingdom's National DNA Database (NDNAD) utilises the European Standard Set of seventeen loci.

The statistical significance of a DNA match is expressed as a Random Match Probability (RMP) or a Likelihood Ratio (LR). The RMP represents the probability that a randomly selected individual from the population would share the same DNA profile as the crime scene sample, while the LR expresses the relative probability of the evidence given two competing hypotheses: that the suspect is the source, versus that an unknown unrelated individual is the source.[13] The proper calculation and presentation of these statistics requires expertise in population genetics, and errors in this process have been a recurring source of concern in forensic casework.

B. Legal Framework in India

The primary statutory basis for the admission of DNA evidence in Indian criminal proceedings is derived from several overlapping legislative instruments. Section 45 of the Indian Evidence Act, 1872, provides for the admission of the opinions of experts on matters of science or art, creating the gateway through which DNA expert testimony is received.[14] Under this provision, the opinion of a forensic scientist regarding the results of a DNA analysis is admissible as expert evidence, and the court is entitled to rely upon such opinion in reaching its conclusions. Section 53A of the Code of Criminal Procedure, 1973 (as amended by the Criminal Law Amendment Act, 2013), specifically authorises the collection of biological samples from an accused person for the purpose of DNA analysis in cases involving sexual offences.[15] This provision was a direct legislative response to the widespread public outrage following the Delhi gang rape case of 2012, and it reflects the legislature's recognition of the particular evidentiary value of DNA evidence in sexual assault prosecutions. The provision authorises the examination of the arrested person by a registered medical practitioner, and the collection of samples for the purpose of determining facts that are relevant to the guilt or innocence of the accused.

The DNA Technology (Use and Application) Regulation Bill, 2019, which was passed by the Lok Sabha but has not yet been enacted into law, represents the most comprehensive legislative

[13]Ian Evett & Bruce Weir, Interpreting DNA Evidence: Statistical Genetics for Forensic Scientists (Sinauer Associates 1998) 47.
[14]Indian Evidence Act 1872, s 45.
[15]Code of Criminal Procedure 1973, s 53A (inserted by the Criminal Law Amendment Act 2013).

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attempt to regulate DNA profiling in India.[16] The Bill proposes the establishment of a National DNA Data Bank and Regional DNA Data Banks, lays down the categories of persons whose DNA profiles may be stored in the databank, and creates a DNA Regulatory Board to oversee the functioning of DNA laboratories and ensure compliance with prescribed standards. The Bill also makes provision for the expungement of DNA profiles in certain circumstances and creates criminal liability for the misuse of DNA information.

However, the Bill has attracted significant criticism from civil liberties organisations and legal scholars. The categories of persons subject to DNA collection under the Bill are extraordinarily broad, encompassing not only convicted persons but also under-trial prisoners, arrestees, and even missing persons and their relatives.[17] Critics have argued that the mandatory collection of DNA from persons who have not been convicted of any offence violates the constitutional right to privacy recognised by the Supreme Court in *K.S. Puttaswamy v. Union of India* (2017), in which a nine-judge bench unanimously held that the right to privacy is a fundamental right protected under Article 21 of the Constitution.

The Bharatiya Nagarik Suraksha Sanhita, 2023 (BNSS), which replaces the Code of Criminal Procedure, has further expanded the scope for forensic evidence collection in criminal investigations. Section 349 of the BNSS authorises the collection of biological samples including DNA for purposes of investigation, reflecting the legislature's commitment to incorporating modern forensic techniques into the criminal process.[18] The provision empowers a magistrate to direct the collection of samples from any person during the investigation of a cognizable offence, subject to safeguards including the presence of a medical professional.

C. Legal Framework in the United States

The admissibility of scientific evidence in American federal courts is governed by Rule 702 of the Federal Rules of Evidence, as interpreted in the landmark trilogy of Supreme Court decisions: *Daubert v. Merrell Dow Pharmaceuticals, Inc.* (1993), *General Electric Co. v. Joiner* (1997), and *Kumho Tire Co. v. Carmichael* (1999).[19] The *Daubert* standard charges the trial judge with the responsibility of acting as a 'gatekeeper' to ensure that proposed scientific testimony is based on a reliable methodology and is relevant to the facts in issue. The criteria

[16]DNA Technology (Use and Application) Regulation Bill 2019 (Lok Sabha Bill No 14 of 2019).
[17]Human Rights Law Network, 'Privacy, DNA and the State: A Critique of the DNA Technology Bill' (2019) HRLN Policy Brief 3.
[18]Bharatiya Nagarik Suraksha Sanhita 2023, s 349.
[19]Daubert v Merrell Dow Pharmaceuticals Inc 509 US 579 (1993); General Electric Co v Joiner 522 US 136 (1997); Kumho Tire Co v Carmichael 526 US 137 (1999).

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articulated by the Court for assessing reliability include whether the theory or technique has been tested, subjected to peer review and publication, has a known or potential error rate, and is generally accepted in the relevant scientific community.

Prior to *Daubert*, the admissibility of scientific evidence in federal courts was governed by the older *Frye v. United States* (1923) standard, which required only that the scientific evidence be based on a methodology that has achieved 'general acceptance' within the relevant scientific community.[20] The *Frye* standard continues to apply in several state courts. DNA evidence easily satisfies both the *Daubert* and *Frye* standards when properly conducted, but controversies over laboratory protocols, mixed profile interpretation, and probabilistic genotyping have generated a series of admissibility challenges in individual cases.

All fifty American states have enacted legislation authorising the collection of DNA from convicted felons, and the federal DNA Fingerprint Act of 2005 extended collection requirements to federal arrestees.[21] CODIS contains over fourteen million offender profiles and has facilitated more than 620,000 criminal investigations. However, the expansion of DNA databases has also raised significant Fourth Amendment concerns regarding unreasonable searches and seizures. In *Maryland v. King* (2013), the Supreme Court held by a five to four majority that the warrantless collection of DNA from arrestees charged with serious crimes was constitutional, analogising the DNA swab to traditional booking procedures such as fingerprinting.[22]

D. Legal Framework in the United Kingdom

The United Kingdom maintains the largest DNA database per capita in the world. The National DNA Database (NDNAD) was established in 1995 following the enactment of the Criminal Justice and Public Order Act, 1994, which created the statutory framework for the collection of DNA from persons arrested or charged with a recordable offence.[23] The Police and Criminal Evidence Act, 1984 (PACE), as amended, governs the procedural aspects of DNA sample collection and retention.

The European Court of Human Rights' ruling in *S and Marper v. United Kingdom* (2008) was a watershed moment in the regulation of DNA databases in Europe. The Court unanimously held that the indefinite retention of DNA profiles of persons who had not been convicted of any offence violated Article 8 of the European Convention on Human Rights, which protects

[20]Frye v United States 293 F 1013 (DC Cir 1923).
[21]DNA Fingerprint Act 2005 (42 USC 14135a).
[22]Maryland v King 569 US 435 (2013).
[23]Criminal Justice and Public Order Act 1994, s 54; Police and Criminal Evidence Act 1984, ss 63–65.

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the right to respect for private life.[24] In response to this ruling, the United Kingdom enacted the Protection of Freedoms Act, 2012, which introduced a system of time-limited retention of DNA profiles and required the deletion of profiles of unconvicted persons in specified circumstances. The admissibility of DNA evidence in English courts is governed by the common law rules of evidence, as supplemented by the Criminal Procedure Rules, 2020. The courts have developed a flexible and contextual approach to the evaluation of scientific evidence, informed by the guidance of the Law Commission's report on *Expert Evidence in Criminal Proceedings in England and Wales* (2011), which recommended the adoption of a statutory reliability standard analogous to the *Daubert* criteria.[25]

IV. LANDMARK CASE LAWS AND JUDICIAL TRENDS

A. International Judicial Landmarks

The pioneering use of DNA evidence in criminal proceedings occurred in the English case of *R v. Colin Pitchfork* (1988), in which DNA profiling developed by Alec Jeffreys was used both to exonerate an innocent man who had falsely confessed to the murders of two young girls, and to identify the actual perpetrator.[26] This case established the transformative potential of DNA evidence in criminal justice and set the stage for its rapid adoption in jurisdictions across the world.

In the United States, the Supreme Court's decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc.* (509 U.S. 579, 1993) established the foundational framework for the admission of scientific evidence in federal courts.[27] Justice Blackmun, writing for the majority, articulated a flexible, multi-factor test for assessing the reliability of scientific testimony, emphasising that the trial judge must ensure that an expert's testimony both rests on a reliable foundation and is relevant to the task at hand. While *Daubert* involved pharmaceutical evidence rather than DNA, its principles have been extensively applied in the DNA context.

The case of *People v. Castro* (545 N.Y.S.2d 985, 1989) represented one of the first serious judicial challenges to the reliability of DNA evidence in the United States.[28] In a pre-trial hearing, Justice Gerald Sheindlin of the New York Supreme Court found that while DNA evidence was generally accepted in the scientific community, the specific DNA testing in the

[24]S and Marper v United Kingdom (2009) 48 EHRR 50.
[25]Law Commission, Expert Evidence in Criminal Proceedings in England and Wales (Law Com No 325, 2011) para 1.19.
[26]R v Pitchfork [1988] unreported; Joseph Wambaugh, The Blooding (William Morrow 1989) 34.
[27]Daubert v Merrell Dow Pharmaceuticals Inc 509 US 579, 597 (1993).
[28]People v Castro 545 NYS 2d 985 (NY Sup Ct 1989).

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case was conducted in an unreliable manner and should not be admitted. This decision signalled that courts would not simply defer to forensic experts but would scrutinise the actual conduct of testing.

The case of *Maryland v. King* (569 U.S. 435, 2013) raised fundamental constitutional questions about the collection of DNA from arrestees.[29] The Supreme Court, in a five to four decision authored by Justice Kennedy, held that the collection of a DNA sample by means of a cheek swab from an arrestee charged with a serious felony offence constituted a legitimate booking procedure and did not violate the Fourth Amendment. Justice Scalia's vigorous dissent, joined by Justices Ginsburg, Sotomayor, and Kagan, warned that the majority's reasoning was pretextual and that the primary purpose of DNA collection was criminal investigation rather than identification.

The English Court of Appeal's decision in *R v. Deen* (1994) provided an early illustration of the statistical dangers of DNA evidence, identifying the 'prosecutor's fallacy' and emphasising the need for expert witnesses to present DNA statistics in a manner that does not mislead the jury.[30] The Court held that the probability of the defendant's DNA matching the crime scene sample by chance should be distinguished from the probability of the defendant's innocence, a distinction that is frequently elided in practice.

B. Indian Judicial Trends

The Supreme Court of India first confronted the use of DNA evidence in the context of paternity disputes in *Goutam Kundu v. State of West Bengal* (1993 AIR 2295), in which the Court held that courts should not compel a party to undergo a blood test for the purposes of establishing paternity, and that such an order could be made only if there is a strong prima facie case of the alleged facts.[31] While this decision predated the widespread forensic use of DNA profiling, it laid down important principles regarding the compellability of persons to provide biological samples.

In *Pantangi Balarama Venkata Ganesh v. State of Andhra Pradesh* (2009) 14 SCC 671, the Supreme Court affirmed the admissibility and probative value of DNA evidence in a murder case.[32] The Court held that DNA evidence, when properly collected, preserved, and analysed, is admissible as relevant evidence under Section 45 of the Indian Evidence Act, and that its probative value is determined by the circumstances of the case and the quality of the underlying

[29]Maryland v King 569 US 435, 465 (2013) (Kennedy J for the majority).
[30]R v Deen [1994] Court of Appeal (Criminal Division), transcript of judgment.
[31]Goutam Kundu v State of West Bengal AIR 1993 SC 2295.
[32]Pantangi Balarama Venkata Ganesh v State of Andhra Pradesh (2009) 14 SCC 671.

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scientific analysis. The Court emphasised the importance of proper chain of custody documentation and the need for expert witnesses to explain the scientific methodology in terms comprehensible to a lay adjudicator.

The case of *Krishan Kumar Malik v. State of Haryana* (2011) 7 SCC 130 further consolidated the judicial acceptance of DNA evidence in Indian criminal proceedings.[33] The Supreme Court upheld the conviction of the accused in a rape and murder case on the basis of DNA evidence linking him to the crime scene, holding that the DNA evidence was corroborated by the other circumstances of the case and was sufficient to establish guilt beyond reasonable doubt. The Court's reasoning reflected a cautious but fundamentally accepting posture toward DNA evidence.

In *Murugan Pillai v. State of Tamil Nadu* (2013), the Madras High Court addressed the question of whether a DNA report prepared by a Central Forensic Science Laboratory (CFSL) expert could be relied upon in the absence of cross-examination of the expert.[34] The Court held that while a DNA report is admissible as documentary evidence, its weight is significantly diminished if the expert is not made available for cross-examination, as the accused has a constitutional right under Article 21 to effectively challenge the evidence against them.

The Supreme Court's decision in *K.S. Puttaswamy v. Union of India* (2017) 10 SCC 1, while primarily concerned with the constitutional status of the Aadhaar biometric identification scheme, articulated a comprehensive doctrine of informational privacy that has significant implications for DNA databasing.[35] The Court held that the collection and storage of sensitive personal data, including biometric information, must be justified by a compelling state interest and must be subject to rigorous procedural safeguards, proportionality requirements, and meaningful remedies for individuals whose privacy interests are violated.

In *Selvi v. State of Karnataka* (2010) 7 SCC 263, the Supreme Court addressed the constitutionality of compelled scientific examination, holding that the involuntary administration of narco-analysis, polygraph tests, and brain electrical oscillation signature tests violated the right against self-incrimination under Article 20(3) of the Constitution.[36] While the Court did not directly address DNA sampling, the principles enunciated in *Selvi* have been invoked in arguments challenging the compelled collection of DNA samples from accused persons, raising important questions about the boundaries of permissible forensic investigation.

[33]Krishan Kumar Malik v State of Haryana (2011) 7 SCC 130.
[34]Murugan Pillai v State of Tamil Nadu [2013] Madras HC unreported.
[35]K.S. Puttaswamy v Union of India (2017) 10 SCC 1.
[36]Selvi v State of Karnataka (2010) 7 SCC 263.

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V. CHALLENGES AND RECOMMENDATIONS

A. Scientific and Technical Challenges

The most fundamental challenge to the reliability of DNA evidence arises from the phenomenon of laboratory contamination. Biological samples are inherently susceptible to degradation and contamination by extraneous DNA, whether from investigators, laboratory personnel, or environmental sources.[37] High-profile contamination scandals, such as the case of the 'Phantom of Heilbronn,' in which DNA from an unidentified woman appeared at numerous crime scenes across Germany and Austria over many years before it was discovered that the source was a factory worker who had inadvertently contaminated the swabs used to collect crime scene samples, have dramatically illustrated the consequences of inadequate quality control in forensic laboratories.

The interpretation of mixed DNA profiles, in which biological material from more than one individual is present in a crime scene sample, poses significant analytical challenges.[38] Conventional STR analysis may be unable to deconvolute the contributions of individual contributors in a mixed sample, particularly where the relative contributions are unequal or where samples are degraded. Software-based probabilistic genotyping tools such as TrueAllele and STRmix have been developed to address this problem, but these tools operate as 'black boxes' that are not fully transparent to defence counsel or the courts, raising serious due process concerns.

The statistical presentation of DNA evidence remains a persistent source of confusion and potential prejudice. The prosecutor's fallacy involves the erroneous equation of the probability of the DNA evidence given innocence with the probability of innocence given the DNA evidence.[39] This error, which constitutes an inversion of conditional probabilities known in statistics as the 'transposition of the conditional,' can cause juries to significantly overestimate the probative value of a DNA match. In India, where the adversarial tradition of expert cross-examination is less well-developed than in common law jurisdictions such as England and the United States, this risk is particularly acute.

[37]Peter Gill, 'Role of Short Tandem Repeat DNA in Forensic Casework in the UK—Past, Present, and Future Perspectives' (2002) 2 BioTechniques S42.
[38]John Buckleton, Christopher Triggs & Simon Walsh, Forensic DNA Evidence Interpretation (CRC Press 2005) 178.
[39]William Thompson & Edward Schumann, 'Interpretation of Statistical Evidence in Criminal Trials: The Prosecutor's Fallacy and the Defense Attorney's Fallacy' (1987) 11 Law and Human Behavior 167.

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B. Institutional and Systemic Challenges

The quality of forensic DNA analysis in India is significantly constrained by institutional weaknesses in the forensic science infrastructure. The Central Forensic Science Laboratory (CFSL) system and the network of State Forensic Science Laboratories (SFSLs) face chronic underfunding, understaffing, and equipment deficiencies that significantly affect the quality and timeliness of forensic analysis.[40] A 2020 report by the Centre for Research and Planning of the Supreme Court of India found that the average pendency period for forensic examination of crime scene evidence in India exceeded six months, with significant backlogs in DNA casework.

The absence of mandatory accreditation requirements for forensic laboratories in India creates significant variability in the quality of forensic analysis across different states and institutions. Unlike the United States, where the DNA Advisory Board and subsequently the Scientific Working Group for DNA Analysis Methods (SWGDAM) have developed comprehensive quality assurance standards for forensic DNA testing, India lacks a single authoritative body responsible for setting and enforcing standards for forensic DNA analysis.[41] This regulatory gap undermines the reliability of DNA evidence and creates opportunities for the introduction of tainted or substandard forensic analysis into criminal proceedings.

Judicial capacity to critically evaluate DNA evidence is another significant systemic challenge. Studies in comparative legal psychology have demonstrated that lay adjudicators, including both juries and professional judges, tend to attribute a high degree of credibility to scientific evidence, particularly when it is presented by individuals who are perceived as experts.[42] The 'CSI effect,' a term coined to describe the influence of forensic science-themed entertainment media on public expectations of the criminal justice process, has been documented in a number of jurisdictions and may contribute to uncritical judicial acceptance of forensic evidence.

C. Recommendations for Reform

The authors propose the following recommendations to address the identified challenges and strengthen the reliability and fairness of DNA evidence in Indian criminal proceedings. First, the DNA Technology (Use and Application) Regulation Bill should be expeditiously enacted after appropriate revision to address the privacy concerns identified by civil society

[40]Centre for Research and Planning, Supreme Court of India, 'Forensic Evidence in Criminal Justice' (2020) CRP Working Paper 7.
[41]SWGDAM, Quality Assurance Standards for Forensic DNA Testing Laboratories (FBI Laboratory 2020).
[42]Tom Tyler, 'Viewing CSI and the Threshold of Guilt: Managing Truth and Justice in Reality and Fiction' (2006) 115 Yale Law Journal 1050.

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organisations and the Supreme Court's doctrine of informational privacy.[43] The revised legislation should include robust provisions for the limitation of DNA data retention, strong penalties for misuse, and meaningful mechanisms for the expungement of profiles of persons who are acquitted or against whom proceedings are dropped.

Second, all forensic laboratories engaged in DNA analysis for criminal investigations should be required to obtain accreditation from the National Accreditation Board for Testing and Calibration Laboratories (NABL) within a specified period. The DNA Regulatory Board proposed in the DNA Technology Bill should be empowered to conduct regular inspections and quality audits of accredited laboratories and to suspend or revoke accreditation in cases of non-compliance.[44]

Third, the courts should be supported in their task of critically evaluating DNA evidence through the training of judges and prosecutors in the principles of forensic science, statistical reasoning, and the interpretation of DNA evidence. The National Judicial Academy should develop and implement continuing education programmes on forensic science for judges at all levels of the judiciary, with particular emphasis on the limitations and vulnerabilities of DNA evidence.[45]

Fourth, the adversarial safeguards applicable to DNA evidence should be strengthened. Defence counsel should be provided with timely access to the raw data, laboratory notes, and methodological parameters underlying a DNA report, and the courts should be alert to the potential for due process violations arising from the use of proprietary probabilistic genotyping software whose internal workings cannot be effectively challenged. Courts should require the disclosure of the source code and validation studies of probabilistic genotyping tools as a condition of their admissibility.

Fifth, India should establish a national post-conviction DNA testing regime, modelled on the Innocence Project in the United States, to enable persons who claim to have been wrongfully convicted on the basis of DNA or other forensic evidence to obtain testing of biological samples that were not available or not tested at the time of trial.[46] Such a regime would not only provide a mechanism for correcting individual miscarriages of justice but would also generate valuable data on the incidence and causes of forensic evidence errors in the Indian criminal justice

[43]Usha Ramanathan, 'DNA, Databases and Surveillance: The DNA Bill' (2019) Economic and Political Weekly 7.
[44]National Accreditation Board for Testing and Calibration Laboratories, Accreditation Criteria for Forensic Laboratories (NABL 2022).
[45]National Judicial Academy, Annual Report 2022–23 (NJA 2023) 45.
[46]Peter Neufeld & Barry Scheck, 'Commentary: Actual Innocence' in James Dwyer, Peter Neufeld & Barry Scheck (eds), Actual Innocence (Doubleday 2000) 356.

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system.

VI. CONCLUSION

DNA evidence occupies a unique and paradoxical position in the landscape of criminal justice. On the one hand, it represents the most scientifically rigorous and individually discriminating form of forensic evidence currently available, capable in principle of identifying the source of a biological sample with near-absolute certainty. On the other hand, the reliability of DNA evidence in practice is profoundly contingent upon the quality of laboratory analysis, the integrity of chain of custody procedures, the accuracy of statistical presentation, and the competence of the courts in critically evaluating the evidence.

The comparative analysis undertaken in this paper reveals that the jurisdictions examined have adopted broadly similar approaches to the admission and evaluation of DNA evidence, grounded in the twin imperatives of scientific reliability and procedural fairness. The United States' *Daubert* framework, the United Kingdom's common law reliability standard, and India's expert evidence regime under the Indian Evidence Act all seek to mediate the tension between the potential evidentiary power of DNA evidence and the risk of miscarriage of justice arising from its misapplication or misinterpretation.

The Indian legal system stands at a critical juncture. The rapid expansion of forensic DNA testing in criminal investigations, driven by technological advances and legislative impetus, has not been accompanied by a commensurate development of the regulatory infrastructure, institutional capacity, and judicial expertise necessary to ensure the reliable and fair use of such evidence. The failure to enact comprehensive DNA regulation, the weakness of the forensic laboratory infrastructure, the underdevelopment of defence resources for challenging forensic evidence, and the absence of a post-conviction DNA testing mechanism collectively create conditions in which the transformative potential of DNA evidence may be subverted by systemic failures.

The authors submit that the path forward requires a multi-dimensional reform agenda encompassing legislative action, institutional strengthening, judicial training, and the development of a robust culture of forensic science accountability. DNA evidence, properly regulated and critically evaluated, can be a powerful instrument of justice. DNA evidence left to operate in an unregulated, under-scrutinised environment poses a serious risk of becoming an instrument of injustice.

As the Supreme Court of India has affirmed across numerous decisions, the right to a fair trial is a fundamental and non-derogable component of the constitutional guarantee of life and

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personal liberty under Article 21. The integration of DNA evidence into the Indian criminal justice system must be guided at every step by fidelity to this constitutional commitment and by the recognition that the quest for reliable, scientifically grounded, and procedurally fair adjudication is not merely a technical aspiration but a fundamental demand of justice.

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