
FORENSIC GENETICS IN CRIME INVESTIGATION IN INDIA

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ABSTRACT

Forensic genetics plays a vital role in modern crime investigation. It bridges the gap between biology and law enforcement and fuses biological science with legal investigations. It helps to uncover the crucial evidence hidden in DNA. Advanced molecular biology techniques analyze the genetic material found at crime scenes, such as blood, hair, skin cells, and bodily fluids. DNA profiling is one of the essential aspects of forensic genetics, which allows investigators to match biological evidence with potential suspects or victims, even in decades-old cases.

With its exceptional accuracy, forensic genetics helps to identify individuals by making a comparison between DNA sequences collected from the crime scene samples and those stored in databases. This has modernized crime investigations and helped to identify the criminal. It also contributed to solving cases once thought insurmountable and helped in acquitting the wrongfully convicted. Furthermore, it plays a significant role in resolving familial disputes and mass disaster victim identification.³

Evolving technologies, such as next-generation sequencing (NGS), help enhance forensic genetics capabilities. It points out how these technologies help analyze and provide more detailed insights into complex samples, like those that have deteriorated over time, which were previously very difficult to interpret. Bioinformatics plays a crucial role in the analysis of genetic data. It helps in expediting the justice delivery process by solving crimes. Forensic genetics ensures the thoughtful use of sensitive genetic information, combined with ethics and law. Though forensic genetics is a powerful component in crime investigation, it also faces various challenges, such as interpretation complexities, privacy concerns, etc.

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³ W. Worrapitirungsi et al., *Assessing the Feasibility of Free DNA for Disaster Victim Identification and Forensic Applications*, 14 SCI. REPS. 5411, 1 (2024).

Forensic genetics mainly represents the fusion of science and justice. It strengthens the crime investigation through the detailed analysis of genetic evidence. As technology advances, its potential continues to expand, and it promises a future where justice is more efficient and accurate. This paper highlights the advancements of DNA profiling, challenges in forensic infrastructure, and legal acceptance of DNA evidence in Indian courts. The paper addresses the lack of a robust legal framework and forensic infrastructure for DNA technology in criminal investigations in India.

Keywords: Forensic Genetics, Crime, Criminal Investigation, DNA

1. Introduction -

A specialized branch of science, namely forensic genetics, applies the principles of genetics for legal investigations, especially in criminal justice. Primarily, the DNA, i.e., the unique genetic blueprint found in every individual, is analyzed to identify the persons involved in crimes, establish biological relationships, or exonerate the innocent. Various sophisticated DNA profiling techniques like Short Tandem Repeat (STR) analysis, mitochondrial DNA analysis, and Y-chromosome analysis have been developed unexpectedly and have revolutionized the field of forensic science globally. Biological evidence, such as blood, saliva, hair, and skin cells collected from the crime scenes, can be matched accurately with the potential crime suspects. Nowadays, forensic genetics is beneficial for crime investigation, and it is a powerful tool for establishing guilt or innocence.⁴

Over the past few decades, the importance of forensic genetics has grown significantly in India. Various institutions like the Centre for DNA Fingerprinting and Diagnostics (CDFD) and state forensic labs have significantly incorporated genetic evidence into the investigation procedures. There is an increase in the usage and acceptance of DNA evidence in cases such as rape, murder, etc. India's commitment to strengthening the role of forensic genetics and addressing privacy and ethical concerns is significantly reflected in recent legal developments, such as the DNA Technology (Use and Application) Regulation Bill, 2019⁵. Nowadays, technologies are continuously evolving, and in this era of technological advancement, forensic genetics stands as a

⁴ Farhat Khanday et al., *Role of DNA Fingerprinting in Crime Detection: Techniques, Applications, and Future Directions*, 10 INT L J. RES. & ANALYTICAL REVS. 154, 155 (2023).

⁵ The DNA Technology (Use and Application) Regulation Bill, 2019, Bill No. 128 of 2019, July. 8, 2019 (India).

backbone of modern crime investigation and increases the accuracy, reliability, and impartiality in the Indian justice system.

In the late 19th and early 20th centuries, scientists began understanding heredity principles through Gregor Mendel's pioneering work on genetics. From that time, the field of forensic genetics started evolving. In the mid-20th century, in 1953, James Watson and Francis Crick discovered the double helix structure of DNA. After that, the application of genetic principles in forensic investigations truly emerged. After this discovery, DNA was recognized as a significant and powerful tool for identifying individuals. In 1985, DNA fingerprinting was developed by Sir Alec Jeffreys', and it significantly revolutionized forensic science. DNA fingerprinting is a powerful tool in crime investigations because it demonstrates that, except for identical twins, no two individuals have a similar DNA pattern. Due to the technological constraints, the early forensic applications were minimal. A new door in forensic science was opened due to Sir Alec Jeffreys' discovery, and it is to solve crimes, settle paternity disputes, and exonerate the wrongly accused.

Forensic genetics rapidly developed with technological advancements within the next few decades. Forensic science helps improve the speed, accuracy, and accessibility of DNA analysis. In the 1980s, Kary Mullis developed a technique, namely Polymerase Chain Reaction (PCR), which helps amplify tiny samples of DNA and analyze highly degraded biological evidence. The area of forensic genetics helps in the creation of individual genetic profiles with high accuracy through short tandem repeat (STR) analysis. DNA databases like CODIS in the United States help law enforcement agencies match the DNA found at crime scenes with the profiles stored nationally. These scientific developments transformed forensic genetics into a pillar of modern crime investigation, and in this era, DNA evidence emerged as a main aid and a decisive factor in the criminal justice system.

The global evolution of forensic genetics can be traced through the following timeline -

PERIOD	MILESTONE	IMPACT ON FORENSIC GENETICS
Mid-19th Century	Gregor Mendel's Heredity Experiments	Laid the scientific foundation for genetic studies and understanding genetic inheritance

1953	Watson and Creek Discover DNA Double Helix Structure	Enabled the molecular understanding of DNA, vital for future forensic applications
1985	Sir Alec Jeffreys' Developed DNA Fingerprinting	Marked the birth of modern forensic genetics and allowed unique identification using DNA
1980s	Kary Mullis Invented PCR (Polymerase Chain Reaction)	Made it possible to amplify tiny DNA samples, revolutionizing crime scene evidence handling
1990s	STR (Short Tandem Repeat) Analysis Introduced	Became the standard technique for accurate and reproducible DNA profiling
1990s	CODIS (Combined DNA Index System) Established in the U.S.	Enabled law enforcement to match DNA evidence with stored profiles i.e., using centralized DNA database in criminal investigations and cold case resolution

Forensic genetics in India has evolved slowly and steadily, but it is a notable journey. However, the country was slow to adopt the technology due to inadequate infrastructure and knowledge. DNA testing was selectively used in a few cases by the end of the 20th century. India's tryst with forensic genetics started hesitantly in the 1990s but picked up in the early 2000s with the setting up of dedicated forensic laboratories, like the Centre for DNA Fingerprinting and Diagnostics (CDFD) in Hyderabad. India's first-ever application of DNA fingerprinting was in the renowned Tamil Nadu child murder case of 1989, for which the man referred to as the 'father of DNA fingerprinting in India', Dr. Lalji Singh, was in charge. There were also some high-profile cases like the murder of Naina Sahni (1995)⁶ and the murder of Priyadarshini Mattoo (1996)⁷, which highlighted the usefulness of DNA evidence, which facilitated greater acceptance in Indian courts. India has subsequently strengthened its forensic capacity, setting up dedicated DNA laboratories

⁶ Sushil Sharma v. The State of N.C.T. of Delhi, 2006 (12) S.C.C. 421 (India).

⁷ Santosh Kumar Singh v. State through CBI, (2010) 9 S.C.C. 747 (India).

and enacting legislation such as the DNA Technology (Use and Application) Regulation Bill, 2019. Today, forensic genetics is poised at a critical crossroads in India, and there is great potential to improve the conviction rates through the use of forensic genetics in crime investigation, along with a daunting task of protecting privacy, regulating and standardizing forensic genetics, and providing ethical rules of its application.

Forensic genetics has grown into an indispensable forensic tool that India's criminal justice system finds too hard to resist with its scientific accuracy, capacity of identifying offenders, saving the innocent from being falsely implicated, and solving high-profile cases. Sexual assault, homicide, and missing person investigations are on the rise; there is a demand for sound, rational, and credible investigative solutions. DNA profiling, in particular, has achieved legal status primarily as a result of numerous 'test' cases and the introduction of the Criminal Procedure (Identification) Act, 2022⁸ that extends the range of biological samples that may be taken.

The evolution of forensic genetics in India can be traced through the following timeline -

YEAR	MILESTONE	SIGNIFICANCE
1989	First DNA Fingerprinting Case - Tamil Nadu Child Murder Case	Dr. Lalji Singh applied DNA fingerprinting for the first time in India - a landmark in forensic science
1990s	Initial Growth Phase	Forensic genetics began to gain traction but faced challenges due to poor infrastructure and awareness
1995	Naina Sahni Murder Case	Use of forensic DNA highlighted its potential in high-profile criminal investigations.
1996	Priyadarshini Mattoo Murder Case	DNA evidence played a pivotal role in public discourse on forensic reliability in courtrooms.

⁸ The Criminal Procedure (Identification) Act, 2022, No. 11, Acts of Parliament, 2022 (India).

2000s	Establishment of Centre for DNA Fingerprinting and Diagnostics (CDFD) in Hyderabad	Government support led to the setting up of specialized DNA labs, increasing forensic capacity.
2019	DNA Technology (Use and Application) Regulation Bill	Proposed regulation to ensure standard practices for DNA data collection, storage, and use.
2022	Criminal Procedure (Identification) Act, 2022	Allowed expanded biological sample collection including DNA for investigative and identification use.

The socio-legal setup of India, with an overburdened judiciary and limitations of conventional investigative tools, has also opened the door to forensic genetics, which shows how to deliver potential and authentic justice on time. With DNA analysis becoming faster and more accessible due to technological developments, forensic genetics has the potential to revolutionize the credibility and efficiency of criminal investigations nationwide.

2. Review of Literature -

Forensic Medicine - the crossroad between science and the law - uses various scientific fields to benefit from the legal process. Of all of these, genetics has turned into a beneficial tool in recent years with advances in DNA profiling. DNA fingerprinting in forensics has transformed forensic science since its introduction in the late 80s. The main emphasis of this approach is on the polymorphism in the mitochondrial and nuclear DNA, especially short length repeats for identification and kinship analysis of the family members.

The paper ‘DNA Evidence: Current Perspective and Future Challenges in India’⁹ is a scientific paper published in the journal *Forensic Science International* that analyses the present practice and prospects of DNA evidence in India. It notes that DNA fingerprinting has been widely adopted worldwide for criminal and civil dispute resolution, individual identification, and determination of parentage. Although Indian courts are closer to using DNA evidence, the source notes that Indian

⁹ S.K. Verma & G.K. Goswami, *DNA Evidence: Current Perspective and Future Challenges in India*, 241 FORENSIC SCI. INT’L 183 (2014).

law does not have clear legal guidelines for the use of DNA profiling in the country, despite current efforts to enact legislation in this field. The implications of the acceptance of DNA as evidence in the Indian courts, along with the laws and ethical perspectives, are discussed in this paper. It also describes the advances of DNA testing and the shortcomings of the test results, noting that DNA profiles are unique, which does not always translate to “beyond a reasonable doubt” evidence. For example, there might be issues such as DNA theft or fakery.

The article ‘Impact of DNA Evidence in Criminal Justice System: Indian Legislative Perspectives’¹⁰ discusses the impact of DNA in the domain of the Indian criminal justice system, by taking Indian legislative perspectives and the necessity of dedicated legislation required for DNA technology. It describes the history of DNA evidence in criminal prosecution and the growing scope of DNA in criminal and civil litigation, including its application to identify plaintiffs and exculpate the innocent. It also looks at the legal issues and ethical dilemmas thrown up by DNA technology in India, which include privacy concerns, rights against self-incrimination, admissibility of DNA evidence in the courts, especially in paternity disputes, and the Indian Evidence Act. Finally, the paper stresses the urgent need for legislative amendments and a separate bill on DNA profiling that will ensure seamless and effective use of such a scientific tool while protecting individual rights and addressing societal problems.

The article ‘Genetic Jurisprudence: Reimagining Indian Legal System’s Approach to DNA Evidence and Privacy Protections’¹¹ analyzes the expanding role of DNA evidence in India’s criminal justice system. It looks at how forensic science, especially DNA, changes the course of criminal investigations and court cases. The paper explores DNA technology’s legal provisions, such as the DNA Technology (Use and Application) Regulation Bill, 2019, and the Criminal Procedure (Identification) Act, 2022. It assesses its impact on individual rights, privacy, and constitutional protection. It underlines the importance of a strong law and ethical deliberations for an even and just application of DNA technology in India.

¹⁰ A. Srivastava et al., *Impact of DNA Evidence in Criminal Justice System: Indian Legislative Perspectives*, 12 EGYPTIAN J. FORENSIC SCI. 51 (2022).

¹¹ V. Nakta & S. Dahiya, *Genetic Jurisprudence: Reimagining Indian Legal System's Approach to DNA Evidence and Privacy Protections*, 63 PANJAB U. L. REV. 130 (2024).

3. Understanding Forensic Genetics -

A specialized branch of forensic science is known as forensic genetics, which applies the principles of genetics to modern crime investigations. It helps find hereditary material in all living organisms by analyzing every individual's DNA (deoxyribonucleic acid). It also helps in the identification of individuals and establishing biological relationships. Forensic genetics links suspects to crime scenes, identifies victims, and exonerates innocent persons.

Dr. R.K.Gorea -

A renowned Indian forensic expert, in his co-authored book 'Forensic Medicine and Toxicology' (published by Peepee Publishers), emphasizes: "Forensic genetics is the practical application of molecular biology and genetic techniques to solve legal issues, particularly in associating biological evidence with individuals involved in criminal cases."

Dr. R.K.Sharma -

A former Director, Central Forensic Science Laboratory, CBI, New Delhi, in his forensic science training modules and public lectures, expresses: "Forensic genetics is the application of modern genetic techniques to resolve legal matters. In criminal investigations, it serves as a tool to establish identity, kinship, and involvement in the crime through biological traces."

Sir Alec Jeffreys' -

A Geneticist and pioneer of DNA fingerprinting, highlights: "Forensic genetics is the application of genetic knowledge and techniques to resolve legal issues, particularly in identifying individuals through their unique DNA profiles."

Sir Alec Jeffreys' groundbreaking discovery of DNA fingerprinting in 1984 revolutionized forensic science by providing a reliable method for linking biological evidence to individuals.

4. Role of DNA in Crime Scene Investigation -

In India, forensic genetics plays a significant role in crime scene investigation. For the identification of the suspects and for establishing the links between the crime, the victim, and the

accused, the field of forensic genetics provides scientifically reliable methods.¹² It helps in examining the biological samples such as blood, saliva, hair, semen, or skin cells, which are collected from the crime scene. Through these biological samples, forensic experts can extract DNA profiles, which serve as unique identifiers for individuals. These unique DNA profiles are compared with the DNA databases or matched directly with the suspects, either to confirm that person's involvement with the crime or to establish the person's innocence. DNA evidence has proven invaluable in the corroboration of testimonies, in the reconstruction of events, and in accurately securing the convictions of the criminals in the cases of missing persons, homicide, or sexual assault. The area of forensic genetics helps enhance the modern investigation procedure and strengthen the judicial process.

5. Legal Framework for Forensic Genetics in India -

Forensic genetics plays a significant role in crime investigations in the modern era. It provides scientific evidence that helps identify the suspects, exonerate the innocent person, and ensure proper justice. Different legal frameworks, such as statutes, judicial precedents, and procedural safeguards, help govern forensic genetics in India. India's legal framework that regulates forensic genetics is a mosaic of various constitutional mandates, procedural codes, statutory laws, and judicial precedents. Still, no single comprehensive statute in India would exclusively govern the field of forensic genetics. Still, several rules and regulatory mechanisms collectively provide the framework for its application.

Constitutional Provisions -

ARTICLE	PROVISION	JUDICIAL INTERPRETATION
20(3) ¹³	Protection against self-incrimination	Selvi v. State of Karnataka (2010) ¹⁴ : An accused cannot be compelled to provide testimonial evidence against themselves and the DNA evidence which are physical and not

¹² Tabasum Ara, *DNA Profiling in Criminal Justice System of India: Relevance and Importance*, 7 INT L J. FOR RES. TRENDS & INNOVATION 117, 119–20 (2022).

¹³ INDIA CONST. art. 20, cl. 3.

¹⁴ Selvi v. State of Karnataka, A.I.R. 2010 S.C. 1974 (India).

		testimonial, it does not violate Article 20(3) of the Constitution of India if it is obtained under procedural safeguards.
21 ¹⁵	Right to life and personal liberty	Justice K.S. Puttaswamy v. Union of India (2017) ¹⁶ : The right to privacy was reaffirmed as a fundamental right of the individual by saying that any intrusion, i.e., collection of DNA samples must be necessary and proportionate and in accordance with law and addressed the need for a clear legal and statutory framework that governs sensitive biometric data, including genetic material.

Indian Evidence Act, 1872¹⁷ -

SECTION	PROVISION	RELEVANCE TO FORENSIC GENETICS
45	Opinion of Experts	DNA experts fall under this and their opinions are admissible in the court.
46	Facts bearing upon Opinions of Experts	Allows the facts not otherwise relevant, are relevant if they support or are inconsistent with the expert's opinion, when such opinions are relevant, e.g., enables DNA related facts to be introduced if they support or contradict expert's opinion.
112	Presumption of Legitimacy of a Child	Nandlal Wasudeo Badwaik v. Lata Nandlal

¹⁵ INDIA CONST. art. 21.

¹⁶ Justice K.S. Puttaswamy v. Union of India, (2017) 10 S.C.C. 1 (India).

¹⁷ Indian Evidence Act, 1872, No. 1, Acts of Parliament, 1872 (India).

		Badwaik (2014) ¹⁸ : DNA can rebut the presumption of legitimacy in marriage.
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Code of Criminal Procedure, 1973¹⁹ -

SECTION	PROVISION	FORENSIC GENETIC IMPACT
53	Medical Examination of the Accused	At the request of a police officer, medical examination of the accused can be done by a registered medical practitioner and it also includes DNA sample collection by a medical practitioner.
53A	Medical Examination of the Rape Accused	Allows for the examination of persons accused of rape and it also includes the collection of semen, blood, or DNA samples.
164A	Medical Examination of the Victim of Rape	Mandates the medical examination of rape survivors and the DNA collection within 24 hours of receiving information.
311A	Power of Magistrate to Order Person to give Specimen Signature or Handwriting	Judicially interpreted to include DNA samples.

¹⁸ Nandlal Wasudeo Badwaik v. Lata Nandlal Badwaik, A.I.R. 2014 S.C. 932 (India).

¹⁹ The Code of Criminal Procedure, 1973, No. 2, Acts of Parliament, 1974 (India).

Introduction of New Criminal Laws in 2023 -**Bharatiya Sakshya Adhiniyam, 2023²⁰ -**

(Replaces Indian Evidence Act, 1872 - Effective from July 1, 2024)

NEW SECTION (BSA, 2023)	OLD SECTION (IEA, 1872)	PROVISION
39	45	Admissibility of expert opinions including DNA experts.
40	46	Facts including DNA related facts that support or contradict expert opinions are relevant.
116	112	Presumption of legitimacy - can be rebutted with DNA evidence.

Bharatiya Nagarik Suraksha Sanhita, 2023²¹ -

(Replaces Code of Criminal Procedure, 1973 - Effective from July 1, 2024)

NEW SECTION (BNSS,2023)	OLD SECTION (Cr.P.C.,1973)	PROVISION
51	53	Medical examination of the accused including DNA sample collection for DNA profiling.
52	53A	Examination of the rape accused, includes blood, semen and DNA samples collection.
184	164A	Medical examination of the rape victim and the DNA collection within 24 hours of receiving information.

²⁰ Bharatiya Sakshya Adhiniyam, 2023, No. 47, Acts of Parliament, 2023 (India).

²¹ Bharatiya Nagarik Suraksha Sanhita, 2023, No. 46, Acts of Parliament, 2023 (India).

349	311A	Magistrate can order the collection of signatures, biological samples, fingerprints, voice and DNA evidence.
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The DNA Technology (Use and Application) Regulation Bill, 2019²² -

Several attempts were made in India to create a comprehensive law in forensic genetics. Among them, one of the most relevant and comprehensive legislative attempts was made in 2019 to regulate forensic genetics. In the year 2019, the DNA Technology (Use and Application) Regulation Bill, 2019 was made, and this bill includes the following -

A. Establishment of DNA Regulatory Board -

The DNA Regulatory Board should be established to oversee the DNA testing laboratories, develop several norms for data usage, and ensure quality assurance.

B. Creation of the DNA Data Banks -

DNA data banks should be created in the national and regional sectors to store profiles from crime scenes, under trials, suspects, missing persons, and volunteers.

C. Use in Specific Cases -

DNA technology can be used in determining various offences like murder, sexual offences, human trafficking, etc., and in civil matters like parentage disputes. The Bill, 2019, listed all those specific categories of offences where DNA technology can be used.

D. Consent and Privacy Safeguards -

The DNA Technology (Use and Application) Regulation Bill, 2019 emphasizes the consent and privacy of the individuals by highlighting that the DNA samples must be collected from the individuals with the permission or judicial authorization. It also restricted access and disclosure to authorized personnel only.

²² The DNA Technology Bill, *supra* note 5.

E. Penalties for Misuse -

To determine privacy breaches, provisions were made for penalties for unauthorized disclosure or misuse of DNA data.

Despite its progressive intent, the Bill, 2019 has faced criticism on the following grounds-

- a. This Bill defines the scope of offences broadly and vaguely.
- b. There is the possibility of surveillance by this.
- c. Genetic data can be misused.

Withdrawal of the DNA Technology (Use and Application) Regulation Bill, 2019 -

The DNA Technology (Use and Application) Regulation Bill, 2019, aimed to regulate the use of DNA technology in India. However, the bill faced criticism regarding the privacy concerns of the individuals and the potential for misuse. The government withdrew the Bill, 2019, from the Lok Sabha in July 2023 and cited that its provisions were largely covered under the Criminal Procedure (Identification) Act, 2022²³.

Identification of Prisoners Act, 1920²⁴ -

(Amended in 2022)

The Identification of Prisoners Act, 1920, was replaced by the Criminal Procedure (Identification) Act, 2022, which expands the scope of data collection:

- A. It authorizes the collection of biological samples, including DNA, from convicted, arrested, or detained individuals.
- B. It enabled these samples to be stored and analyzed for up to 75 years.
- C. Privacy and civil liberty-related concerns are raised, particularly when applied to the undertrials or those not convicted.

²³ The Criminal Procedure Act, *supra* note 8.

²⁴ The Identification of Prisoners Act, 1920, No. 33, Acts of Parliament, 1920 (India).

Personal Data Protection Framework -**The Digital Personal Data Protection Act, 2023²⁵ -**

It is not specific to the field of forensic genetics. However, the Digital Personal Data Protection Act of 2023 contains the principles for processing personal data, including sensitive genetic information. It highlights the following points:

- A. Consent-based collection.
- B. Limitation on the purpose.
- C. Minimization of Data.
- D. Protection of data subject rights.

The need for a data protection framework becomes critical due to the increased use of forensic genetics. Though the Digital Personal Data Protection Act, 2023, is not specific to forensic data, it lays down the general principles for processing personal data, including genetic data. It serves as a reference point until a dedicated DNA law is enacted.

Institutional and Laboratory Regulation -

Forensic Science Laboratories (FSLs) under the Ministry of Home Affairs and some private labs conduct forensic tests in India. Accreditation is provided by the National Accreditation Board for Testing and Calibration Laboratories (NABL), but quality standards are varied due to the absence of a centralized statutory oversight body. The DNA Technology (Use and Application) Regulation Bill, 2019, proposed a DNA Regulatory Board to address this gap.

Government Guidelines -

- A. The government set various national guidelines for DNA Testing Laboratories (by the Department of Biotechnology) to outline the quality assurance practices for forensic labs, but it lacks statutory force.
- B. The government set up various judicial training manuals to train the judges and prosecutors on handling DNA evidence in cases.

²⁵ The Digital Personal Data Protection Act, 2023, No. 22, Acts of Parliament, 2023 (India).

Other Guidelines and Protocols -

India follows various operational protocols apart from the statutory laws which are laid down by the National Accreditation Board for Testing and Calibration Laboratories (NABL), which gave accreditation to the DNA laboratories, the Directorate of Forensic Science Services (DFSS) under the Ministry of Home Affairs, which helps in the standardization of the forensic practices across the state and central labs and the standing order 4/2022 by NCRB, which gave detail guidelines about the DNA profiling, sample collection, and crime scene management. These frameworks ensure technical reliability, but their enforceability without a statutory backbone remains a concern.

6. DNA Profiling Techniques -

A. DNA Profiling -

The most valuable and appropriate scientific technique for identifying individuals based on their unique genetic makeup is DNA fingerprinting, also known as DNA profiling. It helps analyze the specific regions of a person's DNA that vary among individuals. This feature makes it possible to accurately match the biological samples, like hair, blood, semen, or saliva, to a particular person. Nowadays, in India, DNA fingerprinting or DNA profiling has become a powerful tool in the context of crime investigation, and by linking suspects to the crime scenes or by exonerating the innocent, it helps in solving critical cases related to missing persons, rape, murder, etc.

Several DNA analysis techniques are regularly employed in forensic genetics to aid criminal investigations in India. The most widely used and popular DNA analysis method is Short Tandem Repeat (STR) analysis. It is the most potent tool for individual identification because it specifically focuses on the specific regions in nuclear DNA that vary between individuals. Due to its high discriminatory power and effectiveness in matching biological samples such as blood, hair, semen, or saliva collected from crime scenes with the suspects, it is considered the most standard method used in crime labs across India. Another widely accepted DNA analysis method is Y-STR analysis. It targets the markers on the Y chromosome, and particularly, it is beneficial in sexual assault cases or cases that involve male-specific identification, especially when female DNA is present in greater quantity. Another popular DNA analysis method is mitochondrial DNA (mtDNA) analysis. This analysis becomes critical when nuclear DNA is highly degraded or unavailable in hair shafts,

teeth, or old bones, as mtDNA is more abundant and inherited maternally, allowing for lineage tracing. All these techniques enable more accurate and scientifically advanced criminal investigations and form the backbone of forensic DNA analysis in India.

While DNA profiling has revolutionized the procedure of criminal investigation in India, a significant gap persists in its practical and consistent implementation, due to a combination of legal, ethical, procedural, infrastructural, and social factors. One of the main reasons is the absence of a comprehensive legal framework. No act or legislation has long been dedicated to regulating DNA data collection, use, and storage in India. First, in 2003, the DNA Technology (Use and Application) Regulation Bill was proposed, and then in 2018, it was again revised and introduced in the Lok Sabha in 2019, but later it was withdrawn and not passed into law. This leads to uncertainty and inconsistency in application across various jurisdictions. Under the criminal laws, the legal admissibility of DNA evidence depends on the proper procedure and documentation, but those laws were not designed initially for advanced forensic tools like DNA. In India, limited forensic infrastructure, a shortage of fully equipped forensic laboratories (both central and state-run), and a lack of trained personnel created a bottleneck in processing samples. Timely DNA profiling results are delayed due to the pendency of many criminal cases, which overburden the labs. Lack of standardized procedures and protocols leads to the improper collection, preservation, and contamination of biological evidence in crime scenes, which results in unusable or misleading DNA results. However, ethical, financial, and judicial limitations further widen the gap. Concerns about potential misuse of DNA data have been raised due to the lack of regulatory safeguards and profiling without consent, especially in marginalized communities, which is feared to lead to misuse or biased investigations. Also, DNA testing is expensive and time-consuming, and many police departments and investigation agencies have limited budgets, which restricts the regular use of DNA analysis. Moreover, underutilization or misinterpretation of DNA evidence happens because many judges and lawyers are not fully trained in this scientific method. There is societal and cultural stigma that discourages reporting and providing samples for DNA evidence, and also a lack of public trust and awareness about DNA profiling, which creates a gap in its practical implementation. Comprehensive legislation, ethical safeguards, and public sensitization are necessary to bridge this gap.

B. Sample Collection and Analysis -

The collection and analysis of biological evidence play a vital role in the context of DNA profiling techniques in crime investigation in India. It ensures the integrity and accuracy of forensic results. Sterile tools such as swabs, tweezers, and gloves are used to collect biological samples like blood, hair, saliva, skin cells, and semen from the crime scenes to prevent contamination. After the collection, each biological sample is sealed and carefully labelled in a tamper-evident container and documented for the chain of custody. Proper storage, often in refrigerated or temperature-controlled environments, is critical to preserving the DNA's integrity. To create individual DNA profiles, those biological samples undergo various procedures such as DNA extraction, quantification, amplification (commonly using Polymerase Chain Reaction or PCR), and electrophoretic analysis. These profiles are then compared against known samples or databases such as the Combined DNA Index System (CODIS)-like repositories maintained by law enforcement. Adherence to standardized protocols by forensic experts and compliance with the DNA Technology (Use and Application) Regulation Bill, 2019, further enhances the credibility and admissibility of DNA evidence in Indian courts.

India's sample collection and analysis gap arises from systematic, infrastructural, technical, legal, and procedural shortcomings. Many police personnels, first responders, and forensic technicians lack proper training in scientific collection, leading to DNA samples' contamination or degradation. There is also a lack of adequate infrastructure and facilities, as well as access to modern forensic laboratories in many regions of India, predominantly rural and underdeveloped areas, which results in the degradation of the DNA samples. Transportation from the crime scene to the forensic labs, especially in remote regions, sometimes leads to DNA degradation due to heat, moisture, or time exposure. Though the DNA Technology (Use and Application) Regulation Bill, 2019 is critical in this context to provide a framework for sample collection and analysis, it has already been withdrawn from the Lok Sabha. In India, uniform national sample collection and analysis guidelines are lacking across all states. In India, comparative analysis and quick matches of DNA samples are hindered due to the absence of a fully operational and centralized national DNA database. However, several efforts have been made to build a CODIS-like system. There are also budgetary and policy constraints in India regarding sample collection and analysis. Especially at the state level, forensic science, sample collection, analysis, and crime scene investigation often

receive low budget allocations, which limit the expansion, upgradation of labs, sample collection, and investment in human capital and technology.

7. Role of Forensic Genetics in Crime Investigation -

A. Application of Forensic Genetics in Different Types of Crimes -

Forensic genetics has emerged as a significant tool in criminal investigations in India. It helps identify the suspects with scientific accuracy, exonerates the innocent person, and links evidence to specific individuals. It also applies to determining various types of crimes and significantly strengthens the criminal justice system.

a. Homicides -

Forensic genetics plays a significant role in homicide investigations in India. It helps analyze the biological evidence, such as blood, skin cells, or hair, which was left at the crime scene. DNA profiling or fingerprinting helps establish a connection between the suspect and the victim or the crime scene. In India, the usage of DNA testing has increased by forensic labs like CFSLS (Central Forensic Science Laboratories) to confirm the identity of the victims and to link suspects to murders, and strengthen the evidentiary chain.

b. Sexual Assault -

Forensic genetics plays a crucial role in the investigation of cases such as sexual assault. In these cases, biological samples like saliva, semen, or epithelial cells are collected from the victim's body or clothing. DNA evidence helps identify the perpetrator and aids in exonerating the innocent person. In sexual assault cases, India has increased the usage of DNA profiling through various initiatives like the Sexual Assault Evidence Collection Kits (SAECK), which helps in the improvement of the quality of evidence and the speed of the prosecution.

B. Identification of Suspects/Perpetrators -

In India, DNA databases and genetic profiling assist law enforcement in identifying suspects, especially in cases where the offender is untraceable or unknown through conventional means. In India, the proposal of a national DNA database under the DNA Technology (Use and Application) Regulation Bill seeks to streamline this process. DNA collected from crime scenes should be

appropriately matched with the stored profiles to enhance the ability to solve cold cases and repeat offenses.

C. Cold Case Resolution: Use of Genetic Profiling to Solve Long-Unsolved Cases -

Cold cases are being revived with the advent of forensic genetics, which were stagnant due to the lack of leads or evidence. Nowadays, in India, integrating DNA profiling into criminal investigations helps solve crimes that have remained unsolved for decades. Using advanced genetic technologies, minimal biological evidence, which is preserved from the old crime scenes, such as hair strands, blood, or skin cells, can now be reanalyzed.

The field of forensic genetics is now aiding law enforcement in India to create a link between suspects and old crime scenes in such cases, which have historically remained unresolved due to a lack of technological support or investigative lapses. In some of the notable cases, such as sexual assault and murder, DNA preserved in forensic labs has matched with the samples from convicted persons or arrested individuals in recent years, and it has led to long-awaited breakthroughs. Growing DNA databases and advanced laboratory capabilities increasingly support these types of efforts.

Genetic or DNA profiling provides unique identifiers that help in the linking of suspects to crime scenes with high precision. This method has led to significant breakthroughs in the re-examination of the evidence from cold cases, especially in sexual assault and murder cases. One of the prominent examples is the Aarushi Talwar case (2008)²⁶. In this case, DNA evidence played a significant role in the crime investigation and highlighted the potential and the pitfalls of forensic genetics in complex cases.

Moreover, in the investigation of cold cases, the integration of DNA profiling helps to strengthen the evidence base and deter wrongful convictions. The role of genetic profiling in cold case resolution is growing day by day, and the improvement of crime scene management and the expansion of forensic infrastructure by the Indian authorities help in ushering in a more scientifically grounded and efficient justice system.

²⁶ Nupur Talwar v. State of U.P., Crim. A. Nos. 293 & 294 of 2014 (All. HC Oct. 12, 2017) (India).

D. Exonerating the Innocent -

In criminal justice system where wrongful convictions can result from coerced confessions, flawed investigations or mistaken identity, DNA testing has emerged as a powerful and significant tool in exonerating the innocent, especially in a criminal justice system where wrongful convictions can result from coerced confessions, flawed investigations, or mistaken identity. Forensic genetics has been used increasingly to overturn such injustices in India, and it helps to provide objective and scientific evidence that either confirms or contradicts the earlier findings. DNA profiling aids in the reanalysis of the biological samples and leads to the acquittal of individuals who were previously convicted of serious crimes like rape or murder, and highlights its value in safeguarding the fundamental rights of individuals. Nowadays, DNA testing is becoming an essential safeguard against miscarriages of justice and helps reinforce the fairness of the legal process.

8. Numerous Challenges in Implementing Forensic Genetics in India -

Though forensic genetics in India has several potentialities, it also faces various critical challenges. Those challenges are as follows:

A. Inadequate Infrastructure -

Delays in DNA analysis happen because almost all forensic labs in India are overloaded and poorly equipped with adequate infrastructure.

B. Deficiency of Expert Personnel -

Throughout India, there are but a few trained forensic geneticists, and standardized training programs in genetics are lacking in the country.

C. Legal and Policy Vacuum -

In India, the absence of specific and structured law, such as the pending DNA Technology Bill, 2019, has resulted in procedural inconsistencies.

D. Sample Contamination Risks -

Evidence integrity is often compromised in India due to poor handling techniques, storage, and chain of custody.

E. Privacy Concerns -

Robust data protection laws are very much required in today's India to decrease the potential risks to individual rights that arise due to the data collection process.

F. Low awareness level -

Misuse or misinterpretation of DNA evidence can happen in India, because there is a low awareness and limited understanding among police and the judiciary.

G. High Costs and Limited Access -

In India, the widespread use of DNA technology is restricted due to the financial constraints and lack of facilities in rural areas.

9. Landmark Cases -

A. Shri Banarsi Dass v. Teeku Dutta (2005)²⁷ -

This case is related to DNA testing. In this case, it is highlighted that DNA testing can only be ordered in civil disputes, like paternity-related disputes, after careful judicial scrutiny.

B. Selvi v. State of Karnataka (2010)²⁸ -

This landmark case emphasized the need for voluntary consent of the person. In this case, the Supreme Court held that if narco-analysis, polygraph tests, and brain mapping tests are conducted without the permission of the person, then it can violate article 20(3) and article 21 of the Constitution of India.

C. Bhabani Prasad Jena v. Convenor Secretary, Orissa State Commission for Women (2010)²⁹ -

In this case, DNA tests were ordered by the Court, and the need for balancing individual rights and the interest of justice.

²⁷ Shri Banarsi Dass v. Teeku Dutta, (2005) 4 S.C.C. 449 (India).

²⁸ Selvi v. State of Karnataka, A.I.R. 2010 S.C. 1974 (India).

²⁹ Bhabani Prasad Jena v. Convenor Secretary, Orissa State Commission for Women, (2010) 8 S.C.C. 633 (India).

D. Nandlal Wasudeo Badwaik v. Lata Nandlal Badwaik (2014)³⁰ -

This landmark case is related to the paternity dispute. The Supreme Court highlighted the judicial acceptance of forensic genetics as conclusive and held that DNA evidence is so valuable that it can supersede all other evidence.

E. Kanti Devi v. State of Rajasthan (2015)³¹ -

DNA test results were upheld as crucial in determining paternity and resolving family disputes in this landmark case.

10. Future Prospects -

In the Indian criminal justice system, forensic genetics is a transformative and inseparable tool in investigating crimes, leading to more precise, efficient, and just outcomes. Technological advancements, public trust, and legal framework help shape the prospects of forensic genetics in India.

A. Expansion of DNA Databases -

Developing national and regional DNA databases in India is necessary to identify repeat offenders, solve cold cases, and exonerate innocent people.

B. Improved Crime Solving Rates -

Concrete scientific evidence can be provided by DNA profiling. It can also lead to higher conviction rates, especially in cases of homicide, sexual assault, etc.

C. Wider Applicability -

The field of forensic genetics is handy in solving violent crimes in India. It also plays a vital role in tackling organized crime, terrorism, and human trafficking by establishing cross-linkages among the criminal networks through genetic evidence.

³⁰ Nandlal Wasudeo Badwaik v. Lata Nandlal Badwaik, A.I.R. 2014 S.C. 932 (India).

³¹ Kanti Devi v. State of Rajasthan, CW No. 14157 of 2016 (Raj. HC Feb. 2, 2017) (India).

D. Capacity Building and Research Programs -

For increasing research funding, developing indigenous tools, and strengthening human resources in India, there is a strong need for collaboration between the academic institutions, forensic labs, and law enforcement agencies.

11. Recommendations -

A. Legislative Clarity and Enactment -

To safeguard the person's privacy rights, protect personal data, and use DNA information ethically, it is necessary to enact a structured DNA-related law.

B. Infrastructure Enhancement -

For the betterment of forensic genetics, it is necessary to modernize the forensic laboratories and enhance the infrastructure.

C. Training Programs -

Regular training for police personnels, prosecutors, and forensic experts are necessary for collecting, preserving, and interpreting DNA evidence and maintaining evidentiary integrity.

D. Public Awareness and Ethical Safeguards -

Public awareness campaigns are necessary to educate people about DNA evidence's benefits and limitations. It is also required to implement ethical safeguards to prevent the misuse or bias in DNA evidence and strengthen the mechanisms.

E. Inter-agency Coordination -

To ensure the integration of forensic genetics into investigative frameworks, law enforcement agencies, forensic experts, the judiciary, and policymakers need to collaborate.

F. Judicial Reforms and Guidelines -

Uniform judicial guidelines should be formulated to avoid inconsistencies in the trial outcomes and for the admissibility, interpretation, and valuation of DNA evidence.

12. Conclusion -

Forensic genetics stands at the intersection of the field of science and justice. In India, crime investigations have been revolutionized by the ability of forensic genetics to connect suspects with evidence through DNA analysis. In India, forensic genetics is an essential and effective tool for unraveling the truth beneath the crime scenes. It also helps to exonerate the innocent person and strengthen the judicial process's integrity. India is now struggling with various types of complex legal, technological, and ethical issues, so there is a need for continued refinement of forensic genetic implementation, which is supported by legislative reforms, modern infrastructures, and skilled expertise for promising a better future where justice is not just delivered but also scientifically corroborated.

Forensic genetics has become an indispensable and valuable component in the modern crime investigation in India, significantly contributing to the accuracy of criminal justice delivery. DNA profiling plays a significant role in identifying the suspects, exonerating the innocent, and resolving long-pending cases. In India, due to the infrastructural limitations, shortage of skilled professionals, delayed case processing, and ethical concerns related to data privacy and misuse, the effective implementation of forensic genetics techniques still faces several obstacles. These challenges must be addressed through policy reforms, investment in forensic infrastructure, and adherence to ethical guidelines. Forensic genetics can be integrated into the investigative framework to enhance the pursuit of justice and reinforce the public's confidence in India's legal system.

In this dynamic collaboration between genetics and law enforcement, India has the scope to carve a new path where science sheds light on the shadows of crime and guides society toward greater transparency, accountability, and human rights protection. With each strand of DNA, a story unfolds that is not about guilt or innocence, but of a nation embracing truth through innovation.