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DNA PROFILING: A MAGIC BULLET OR A WONDERLAND OF UNCERTAINTY

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Abstract: ***DNA profiling has attained the role of being an established part of the criminal justice process with high admissibility rates in the courtroom. With the advancements in science and technology, it has acted as a promoter in the shift in scientific innovation, ranging from health, economics, and security; to trade, sustainability and justice. Locard's Exchange Principle based on the fact that every contact leaves a trace offers a standpoint to DNA profiling based on the promise of 99% certainty and reliability. Unfortunately, the scientific promise of DNA has dark sides in its application to courtrooms. With a backdrop to DNA processes like PCR, RFLP, CAE and MCE; the paper analyzes the DNA transfer stages and profile matching techniques - Comparison, Random Match Probability and the Likelihood Ratio.[1] Dwelling into the hierarchy of propositions, the paper offers an insight into the 3 models of DNA interpretation: Legal, Liberative and Scientific. From the legal perspective, the International and National legislative backing is discussed in lines with contested rights of fair trial, presumption of innocence, privacy, integrity and autonomy. This research unraveled the cynicism of DNA profiling by diving into the issues of the CSI effect and the landmark Castro case. Issues of contamination, inaccurate results, error rates, probability statistics, interpretation standards quality samples, examiners' bias, laboratory slope and the Hardy-Weinberg equation is assessed.[2] Miscarriage of courts to uphold the Frye and Relevancy Test are deciphered with an aim to showcase the problem of the 'infallibility proposition.[3]Taking from the experience and lessons from judicial pronouncements, the paper concludes with forensic and legal recommendations to uphold the probative and evidentiary value of DNA profiling.***

Keywords: ***Castro case, DNA, Frye case, Human rights, Match probability***

I. INTRODUCTION

Technology has taken the shape of being a 'fit-for-forensic-purpose' wherein its efficiency and credibility is established for criminalistic interpretation.[1] Forensic Science as a field is the application of natural science having its application to the domains of law. Based on principles and methods of traditional science, the field of forensic science ranges to include forensic medicine, psychiatry, toxicology, radiology, odontology, entomology, engineering, climatology and criminalistics. Technological advances have aided to connect the forensic laboratory to the crime scene, generating infallible findings strengthening its evidentiary value in the court.[2] Over the past 30 years, DNA profiling has undergone a significant revolution. Fingerprints were the earliest methods for human identification as formulated by Sir Francis Galton. From the minimum need of a 2 cm blood stain to recovering DNA from a postage stamp or cigarette butt; DNA has shifted from an expensive process to a regular practice.

DNA as discovered by James Watson and Francis Crick stands for deoxyribonucleic acid, twisted double helix polymer made from monomeric units. It comprises 4 nucleotides - Adenine, cytosine, guanine and thymine; these units as informational units referred to as genes. A DNA sequence differs for all individuals, exception being identical twins.[3] A DNA

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[1] Narem V. N. S. S. Usha Amulya, *DNA Profiling & Forensic Science: From Tracing Evolutionary Discoveries to the DNA Technology (Use & Application) Regulation Bill, 2018*, 9 Supremo Amicus 163 (2019).

[2]Aparna Tripathi & Anurag Anand, *DNA Forensic: Controversy, Relevancy and Admissibility*, 3 Supremo Amicus 124 (2018).

[3] Amankwaa, A. O., & McCartney, C., *The effectiveness of the current use of forensic DNA in criminal investigations in England and Wales,* WIREs Forensic Science (Vol. 3, Issue 6) (2021). https://doi.org/10.1002/wfs2.1414

[1] The Royal Society of Edinburgh., *Forensic DNA Analysis: a Primer for Courts,* (2017). https://royalsociety.org/-/media/about-us/programmes/science-and-law/royal-society-forensic-dna-analysis-primer-for-courts.pdf

[2] Heinemann, T., Lemke, T., & Prainsack, B., *Risky profiles: Societal dimensions of forensic uses of DNA profiling technologies,* New Genetics and Society, Vol. 31, Issue 3, pp. 249–258 (2012), https://doi.org/10.1080/14636778.2012.687132

[3] Jordan, D., & Mills, D. E., *Past, Present, and Future of DNA Typing for Analyzing Human and Non-Human Forensic Samples,* Frontiers in Ecology and Evolution (Vol. 9) (2021). https://doi.org/10.3389/fevo.2n021.646130

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Profile is formulated from a scientific process based on the body fluids and cellular material from the crime scene. For instance, hair, blood, semen, soft tissues, bone, teeth, urine, tears, skin, phlegm, feces and saliva. The concept of DNA profiling was first formulated by Alec Jeffreys based on the idea that human beings can be differentiated on the basis of their detectable and reliable differences.[4]

Forensic Science deals with examining the parts of DNA variables which are unique between individuals. The part examined in the DNA is the 'locus' (loci) which acts as a differentiating factor along the DNA chromosome in a specific sequence of bases.[5] These are termed as questioned samples from which a DNA profile is formed and compared to that of the suspect, complainant, other people regularly accessing the location of crime and family members. DNA profiling has been used in cases of paternity testing, mass disaster events, post mortem analysis, identifying perpetrators in cases of rape, murder, sexual abuse and missing person's investigation. The first country to use DNA profiling in a criminal case of Colin Pitchfork in 1986 was United Kingdom.[6] DNA played a crucial role in even in the OP Simpson murder trial. The method used back then was a RFLP (Restriction Fragment Length Polymorphism) encompassing- DNA extraction, DNA restriction, Gel electrophoresis, Southern blotting and Hybridization.[7]

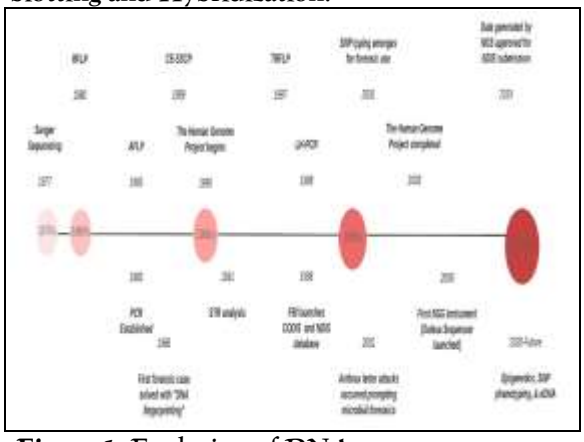

Figure 1: Evolution of DNA

II. LITERATURE REVIEW & RESEARCH GAP

Sr. No.	Research Paper	Literature Review	Research Gap
1.	Forensic DNA Profiling in the 21st Century - Alan L. Friedman	The paper analyzes the evolution of DNA technology from an expensive and rare use to a routine practice in today's time. The remarkable progress in the 21st century with DNA profiling technology such as capillary array electrophoresis, mass spectrometry and microchip capillary electrophoresis is analyzed. With the process of DNA profiling and advantages, the DNA database in USA and Europe have been discussed in	Despite the lucid language and insight into the contemporary DNA Profiling, the paper neglects the dynamic DNA phenotyping to compose a description of the suspect. Supplementing the data protection and privacy, the paper does not shed light on stigmatization and discrimination. The 'slippery slope' argument has not been given any importance.

[4] Hoeffel, J. C., *The Dark Side of DNA Profiling: Unreliable Scientific Evidence Meets the Criminal Defendant*, Stanford Law Review, 42(2), 465(1990). https://doi.org/10.2307/1228965.

[5] Michael Lynch, at all, *Truth Machine: The Contentious History of DNA Evidence* (Chicago: University of Chicago Press, 416 pp. (2008), ISBN 0-226-49806-9.

[6] Machado, H., & Granja, R., *DNA Technologies in Criminal Investigation and Courts. Forensic Genetics in the Governance of Crime*, 1, 45–56 (2020). https://doi.org/10.1007/978-981-15-2429-5_4.

[7] Chambers, G. K., Cordiner, S. J., Buckleton, J. S., Robertson, B., & V, G. A., *Forensic DNA Profiling: The Importance of Giving Accurate Answers to the Right Questions*, 8(3), 445–459 (1997).

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		light of the need to balance the legal framework with the privacy and confidentiality contentions	
2.	The future of forensic DNA analysis - John M. Butler	Rapid DNA testing had led to expansion of STR loci for human identification in Europe and USA. The author analyzes how far DNA testing has come over the past 3 decades and examines where DNA testing will be heading in the next decade. Next generation sequencing on alleles with expanded capabilities have been addressed. Emphasis is laid on the challenges and opportunities in the future of forensic DNA, while seeking the improvement of interpretation in	Irrespective of the evolution over the past 30 decades, the author does not examine the gap and failure rates of DNA Profiling. Issues such as over-representation of indigenous people in databases, impacts on juveniles, DNA procedures, role of ethnicity in formulation of databases and the inferential statistics modeling have been left out of the research's scope.
		complex DNA profile cases.	
3.	DNA Technologies in Criminal Investigation and Courts - Helena Machado & Rafaela Granja	DNA profiling has taken a key role in the criminal justice system. With genetic technology increasing, DNA profiling holds high untapped evidentiary value to be used in courts. The paper describes DNA technology and its use in criminal investigation and proceeding. Taking a slight drift busting the infallibility myth, light is shed on the role of media and its portrait of forensic genetics within the social nature.	In practice, the DNA controversy, relevance and admissibility in the judicial framework needs to be examined. Recent insights into the DNA Bill, 2018 and 2019 have not been dealt with requiring the success rates of common articles to be adjudicated. There is a lack of cross-disciplinary approach between various fields such as the socio-legal debate is untouched.

III. RESEARCH PROBLEM & OBJECTIVES

Based on the existing research and literature, this paper aims:

i. To assess the DNA profiling processes ranging from PCR and RFLP to CAE and MCE.

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ii. To analyze the DNA transfer system and Profiling Matching based on comparison method, Random Match Probability and Likelihood Ratio.
iii. To discuss the hierarchy of proposition and contamination aligned with the 3 DNA models of interpretation (Legal, Liberation and Scientific).
iv. To dwell into the legal stance based on the rights violated (fair trial, presumption of innocence, self-incrimination, integrity, privacy, autonomy) along with the international and national framework in light of the contemporary DNA Bill, 2019.
v. To shed light on the dark side of DNA through the CSI effect and issues such as contamination, laboratory slop, inaccurate results, error rates, visual interpretation, quality sampling, probability statistics, examiner bias and the Hardy-Weinberg equation.
vi. To suggest recommendations based on the failures of the Frye and Relevancy test: both from the standpoint of the scientific and legal arena.

IV. FORENSIC PROCESS - DNA PROFILING

Forensic science investigation typically includes[8]:

i. Recognition - Segregate important components and informative facts from the unrelated and background information.
ii. Identification - Classification of items into varied categories and classes based on its physical properties, chemical composition and biological derivatives.
iii. Comparison and Classification - Comparing class characteristics of evidence with existing standards.
iv. Individualization - Singling out the particular sample to be unique among the same class.
v. Reconstruction - Results of the crime scene investigation, laboratory examination and other sources to be formulated for reconstructing the case events.

While the RFLP prevalent from the Pitchfork case is common, newer techniques have been developed. The Polymer Chain Reaction (PCR) has developed post the Spencer v. Commonwealth of Virginia[9] case due to its speed and high sensitivity. DNA Profiling encompasses an enlargement of serology which specifically deals with blood.[10] While human hair has been often found in crime scenes, it does not contain the nuclear DNA, therefore cannot be typed using the PCR or RFLP methods. But human hair contains mitochondrial DNA which has been used for the first time in the State of Tennessee v. Paul Ware[11] case resulting in a perfect match.

1. DNA Transfer - 'Touch DNA' is primarily transferred by touch rather than the conventional notion of transfer by specific body fluids.[12] Such DNA often results in its presence for a steady period of time and scientific evaluation on the time frame of the deposition is unclear. But all touches do not result in a DNA transfer as it is dependent on factors such as: person to person variability, duration of contact, washing of the contact (example: washing hands), intensity of contact (brief touch or robust handshake) and surface of contact. Apart from these factors, alternative explanations for DNA transfer are based on the kind of transfer.[13]

i. Transfer from A to object - direct/ primary transfer
ii. Transfer from A to B. Transfer from B onto object - secondary transfer
iii. Transfer from A to object 1. Transfer from object 1 to B and then to object 2 - tertiary transfer

[8] Subhash Chandra Singh, *DNA Profiling and the Forensic use of DNA Evidence in Criminal,* Indian Law Institute Stable 53(2), 195–226 (2011), https://www.jstor.org/stable/43953503.
[9] 1989 Va. LEXIS 147, WL 109529 (1989).
[10] Gabel, J. D., *Realizing Reliability in Forensic Science from the ground up,* The Journal of Criminal Law and Criminology, Vol. 104, (2019) No. 2 (Spring Stable URL: https://www.jstor.org/stable/44113391 REALIZING RELIABILI. 104(2), 283–352.
[11] 75 S.W.3d 165 (Ark. 2002).
[12] Kloosterman, A., Mapes, A., Geradts, Z., van Eijk, E., Koper, C., van den Berg, J., Verheij, S., van der Steen, M., & van Asten, A., *The Interface between Forensic Science and Technology: How Technology Could cause a Paradigm Shift in the Role of Forensic Institutes,* The Criminal Justice System, Philosophical Transactions of the Royal Society B: Biological Sciences, 370(1674) (2015). https://doi.org/10.1098/rstb.2014.0264
[13] Lempert, R., *DNA, Science and the Law: two cheers for the Ceiling Principle,* Jurimetrics (Chicago, Ill.), 34(1), 41–57 (1993).

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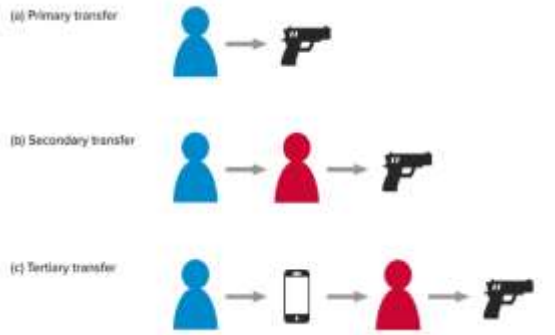

Regardless of the type of transfer, traces of A's DNA might be obtained from the object; whether in direct contact or not. Further, it could be possible that B's DNA traces are not present on the recovered object despite its direct contact. Therefore, it is not possible to determine when the DNA was deposited. Secondary and tertiary transfer may result in deposition of DNA despite 'no touch' per se. It is presumed that with each transfer the quantity of DNA is likely to be reduced but the quantity in a DNA profile cannot rule out the type of transfer as it is dependent on the starting material.

2. DNA Process - DNA is generally represented as a numerical code and analyzed through STRs (short tandem repeats) based on which visualization is provided on an electropherogram.[14] DNA profile generating process is as follows: laboratory examination of item submitted to locate bloody fluids, recovery of body fluid, evaluation of sample, DNA extraction, establishment of DNA through quantification, Amplifying of STR regions using PCR, separation of PCR by size, detection of PCR products and data interpretation.[15] The FLP method is based on breaking the DNA into fragments and adding a restriction enzyme. The PCR method uses the process of amplification of genetic information by a billion times for analysis. New technologies have been developed which include CAE (Capillary Array Electrophoresis), MCE (Microchip Capillary Electrophoresis) and the Matrix Assisted Laser Ionization/Desorption Mass Spectrometry.[16]

Analysis technique	Basis of differentiation	Advantages	Disadvantages
Restriction Fragment Length Polymorphism (RFLP)	Restriction site sequence and fragment length	- High power of discrimination - Reproducible - No prior sequence information required - Can differentiate between homozygotes and heterozygotes	- Time-consuming - Partial digests - Need at least 10–25 ng of DNA - Genetic mutations only identified at restriction cut sites - Not ideal for whole genome variation identification - Requires radioisotopes
Amplified Restriction Fragment Length Polymorphism (AFLP)	Restriction fragment length	- Reproducible - Amplify small amounts of DNA - Species ID not known - Detects dominant bi-allelic markers - No prior sequence information required - Uses capillary electrophoresis techniques	- Time-consuming - Partial digests - Multiple steps can lead to unreproducible results - Genetic mutations only identified at restriction cut sites - Not ideal for whole genome variation identification - Unable to differentiate between heterozygous and homozygous alleles
Terminal-Restriction Fragment Length Polymorphism (TRFLP)	Restriction fragment length	- Less complex results - Amplicon based PCR - Uses capillary electrophoresis technique	- Partial digests - Genetic mutations only identified at restriction cut sites - Peaks can be representative of more than one species - Not ideal for whole genome variation identification
Length Heterogeneity PCR(LH-PCR)	Gene fragment length	- Easy, fast results - Reproducible - Uses universal primers - Uses capillary electrophoresis techniques - Provides a quick screening or monitoring tool for community changes	- May underestimate community/mixture complexity - Lack of database hinders species identification - PCR bias can reduce detection of lower DNA template concentrations
Short Tandem Repeat (STR)	STR fragment length	- Fast - Highly reproducible - High level of discrimination, codominant alleles - Standardized across forensic laboratories - Uses low DNA amounts for amplification - Database of genetic profiles and allelic frequencies for statistical comparisons	- Mixture deconvolution not easy - PCR artifacts can complicate results - Challenges with highly degraded or low template DNA
Short Tandem Repeat (STR)	STR fragment length	- Fast - Highly reproducible - High levels of discrimination, codominant alleles - Standardized across forensic laboratories - Uses low DNA amounts for amplification - Database of genetic profiles and allelic frequencies for statistical comparisons	- Mixture deconvolution not easy - PCR artifacts can complicate results - Challenges with highly degraded or low template DNA
Sanger Sequencing	Sequences every base	- Gold standard for sequence analyses - Uses capillary electrophoresis techniques	- Low throughput - Only 500–700 bases sequenced at a time - Cannot sequence mixtures without cloning
SNaPshot™	Single base changes	- Detects bi-allelic and multi-allelic SNP markers - Able to distinguish between heterozygotes and homozygotes - Human SNP database for statistical comparisons	- Time-consuming - Need to know SNP sequence in advance to design primers - Multiple markers required for high level of discrimination
Single-strand Conformational Polymorphism (SSCP)	2° structure of single-stranded DNA caused by base changes alters strand migration on CE	- Simple - High specificity - Screen potential variations	- Short fragments - Temperature-and mutation sensitive - Nucleotide change not identifiable - DNA strands can reanneal after denaturation affecting mobility during electrophoresis
Next-Generation Sequencing (NGS)	Massive parallel sequencing using various technologies	- High throughput - Discriminative markers - Sequence entire genomes/metagenomes - Simultaneous detection of STR amplicon lengths and SNPs within the amplicon - Used for any DNA (human, non-human, viral, microbial)	- Massive data output that may be challenging to analyze - Analysis algorithms not standardized - Difficult with some technologies to analyze metagenomes to species level

3. DNA Profile Match - Profiles can be analyzed in 3 key ways: Comparison Process, Match Probability and the Likelihood Ratio.[17]

i. Comparison Process - Considered the best method of DNA interpretation as the scientific interprets the crime

[14] Statistics, M. & Donald A. Berry, *Inferences Using DNA Profiling in Forensic Identification and Paternity Case*, Statistical Science, Vol. 6 , No . 2 (May, 1991), pp. 202-205.
[15] Prainsack, B., & Kitz Berger, M., *DNA behind bars: Other ways of knowing forensic DNA technologies*, Social Studies of Science, 39(1), 51–79(2009). https://doi.org/10.1177/0306312708097289
[16] John T., Sylvester & John H. Stafford, *Judicial Acceptance of DNA Profiling*, 60 FBI L. Enforcement Bull, 26 (1991).
[17] Elizabeth A. Bennett & Robert S. Anderson, *DNA Profiling*, (1991) 49 Advocate (Vancouver) 63.

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sample primarily, followed by documentation of the findings. Post interpretation of the crime sample, the interpretation of any known samples takes place before comparison between the two. The process ensures risk of confirmation bias and the crime DNA and sample DNA are interpreted in isolation to establish its source.

ii. Random Match Probability - It is a statistic which estimates the likelihood of randomly selecting individuals from a population by chance. Evaluation of the statistical weight of matching a DNA profile between the STR profiles implies: Either the suspect is the source of the material, or the material came from a third party whose DNA profile is identical to the suspect or the match is a false positive due to an error or contamination. For establishing the weight of evidence post a match the profile is generated from data and statistics to be presented in court in a fair and reasonable manner for avoiding overstatements as to the strength of evidence. UK has a cap on the match probabilities as it becomes difficult to test the assumptions in a calculation and the reeling meaning of numbers in trillions is difficult to comprehend.[18]

iii. Likelihood Ratio - This is based on the probability of obtaining the genetic similarity under a hypothesis associated from the prosecution view versus that of the defense view. It is the match probability for well-amplified profiles from a specific individual. Similar to the cap on match probabilities, the UK has a cap on the likelihood ratio to be reported in one billion.[19]

4. Hierarchy of Propositions - It takes the premise that evidence from the scientific domain may only be interpreted if at least 2 competing propositions are considered. The propositions are on 4 key levels: Offense, Activity, Source and Sub source.[20] The top level assumes that an offense has been committed and the ones seen by the judge. Second level represents activity wherein scientists need to address the given information in a case circumstance. For instance: considerations of transference and persistence. The third level comprises propositions associated with the origin of recovered material. Sub-source level proposition implies scientists are unable to give a substantive opinion on the source of DNA or its transfer.

5. Contamination - Contamination refers to the introduction of DNA or biological material comprising DNA to the existing DNA sample after it has been handed to a trained responsible officer. Complex DNA samples mean a sample lower than optimal, poor quality, degraded or supplemented with a mixture. These scenarios often led to a stance where no interpretation can be effectively formulated with the level of variability.[21] The biological evidence is collected, transported and stored carefully; best preserved in dry or frozen form to avoid contamination. Mixed profiles lead to scenarios which have called for a 'low-template DNA analysis' wherein methods are used to boost the analysis by altering the analysis method to enable good results from lower quantities of DNA.[22] DNA profiling requires constant supervision and must ensure all disposable items and chemicals are used in the analytical process to ensure its exclusivity from DNA. The International Organization for Standardization in 18385:2016 laid down a universal standard to be followed for DNA-free items and all precautions to be undertaken by the police and laboratories.[23]

V. LEGAL STANCE ON DNA PROFILING

The DNA test is considered to have 99.9% chances of correct conclusions but without an adequate legal framework backing it, it becomes difficult for individuals to present their fair stance. Constitutional dimensions such as immunity from Self-Incrimination and Right to

[18] Butler, J. M., *The Future of Forensic DNA analysis*, Philosophical Transactions of the Royal Society B: Biological Sciences, 370(1674), 1–10 (2015). https://doi.org/10.1098/rstb.2014.0252.

[19] *DNA Technology in Forensic Science*. (1992) https://doi.org/10.17226/1866.

[20] Friedman, A. L., *Forensic DNA profiling in the 21st century*, International Journal of Offender Therapy and Comparative Criminology, 43(2), 168–179 (1999). https://doi.org/10.1177/0306624X99432004

[21] Henry C. Lee, *Forensic Science and the Law*, 25 CONN. L. REV. 1117 (1993)

[22] Walsh, S. J., *Legal perceptions of forensic DNA profiling: Part I: A review of the legal literature*, Forensic Science International, 155(1), 51–60(2005), https://doi.org/10.1016/j.forsciint.2004.11.001

[23] Faber, M., *Thirty Years of DNA*, Nature Biotechnology, 1(4), 314–314 (1983), https://doi.org/10.1038/nbt0683-314a

Privacy have been opened and decided by the judiciary solely.[24] From a criminal standpoint, Section 45 of the Indian Evidence Act covers evidentiary value of expert opinion. While no straightforward approach exists for determining the evidentiary value and legal relevancy of DNA, the conclusiveness of a DNA test is accepted worldwide. Interpretation of DNA encompasses 3 key models:[25]

i. Legal Model - Hinges on the need to convict the guilty
ii. Libertarian Model - Do the utilitarian benefits of DNA have the strength to outweigh rights of the accused
iii. Scientific Model - Rests on traits of sampling, probability theories and error rates

India recently in the 271st Law Commission released a report '*Human DNA Profiling - A Draft Bill for the Use and Regulation of DNA-based Technology.*'[26] DNA sampling in India as of now can be seen through different existing frameworks as the void for a specific legislation seems unbridged.

Section 112 of the IEA, 1872 deals with the presumption of legitimacy proof in cases of subsisting marriage. In such scenarios, DNA can be used to determine the paternity of a child and address issues of legitimate paternity. In Nandlal Badwaik v. Lata Badwaik[27], the court held that a DNA test prevails over the presumption of conclusive proof under S. 112. But as a caution, Goutam Kundu v. State of WB, stated that a blood test and DNA test cannot be ordered as an ordinary recourse; it must be backed with a strong prima facie case. Section 73 encompasses comparison of signature, writing or a deal; in such context handwriting sampling can be viewed as a DNA test. Supplementing this, Section 311-A CrPC empowers the Magistrate to order an individual to provide specimens of signatures and handwriting.

Diverting from the IEA, Section 53 of CrPC deals with examination of accused by a medical practitioner. This section has taken the wider connotation of including DNA tests of accused. Post the 2005 amendment and insertion of Section 53A, a rape accused can be examined along with collection of bodily substances such as blood-stains, swabs in sexual offences, finger nail clippings, semen, sweat, hair samples and sputum [Explanation to Section 53A]. The court in Shreemad Jagadguru v. State of Karnataka[28], upheld the constitutional validity of Section 53A. Judiciary has observed DNA testing to supplement and facilitate prosecution to prove the case against the accused as held in *Krishna Kumar Malik v. State of Haryana*[29]. Section 164A of CrPC encompasses medical examination of a rape victim. DNA profiling is considered useful of determining offences of rape under S. 375 & 376 IPC, 1860. Delhi Commission for Women v. Delhi Police[30], mandated use of a SAFE Kit for use by all medical personnel for collection and preservation of DNA samples in sexual assault cases to avoid contamination. Section 293 CrPC envisages reports of certain government scientific experts used as evidence to not be examined as a witness. But the scope and application of DNA profiling in such scenarios is unclear.

DNA profiling gains significance in Section 125 CrPC dealing with maintenance of wives, children and parents. To determine the biological relations and determine paternity in cases of maintenance, DNA can be utilized effectively as evidence. Supplementary to this, Section 7 of the Family Courts Act deals with the jurisdiction of Family Courts to decide the legitimacy of a person and decide maintenance, eventually encompassing the use of DNA techniques. Apart from maintenance, Section 13 has allowed DNA to creep in for dealing with grounds of divorce being - adulterous relationship. In Dipanwita Roy v. Ronobroto Roy[31], a DNA test was ordered for proving or disproving the adulterous relationship. In a landmark case, in Sharda v. Dharmpal[32], the court held that a DNA test may be ordered in divorce proceedings.

The constitutional validity of DNA testing has been challenged a number of times, on the contention that it is violative of Article 20(3) and 21.[33] The court in a 11-judge bench decided

[24] Daves, A., *The Use of DNA Profiling and Behavioural Science in the Investigation of Sexual Offences*, Medicine, Science and the Law, 31(2), 95–101 (1991), https://doi.org/10.1177/002580249103100202

[25] Lynch, M., *God's signature: DNA profiling, the new gold standard in forensic science,* Endeavour, 27(2), 93–97 (2003), https://doi.org/10.1016/S0160-9327(03)00068-1

[26] Walsh, S. J., *Evaluating the role and impact of forensic DNA profiling on key areas of the criminal justice system,* Department of Chemistry - Materials and Forensic Science, 427 (2009), http://hdl.handle.net/10453/34080

[27] 2014 (134) AIC 17.

[28] Writ Petition No. 43825 of 2014 (GM-RES).

[29] 2011 AIR SC 2970.

[30] S.L.P. (Crl.) No. 2506 of 2009.

[31] 2014 (144) AIC 110.

[32] AIR 2003 SC 3450.

[33] Gardiner, G., '*Racial Profiling': DNA Forensic Procedures and Indigenous People in Victoria. Current Issues in Criminal Justice*, 17(1), 47–68 (2005), https://doi.org/10.1080/10345329.2005.12036335

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the issue in State of Bombay v. Kathi Kalu Oghad[34] wherein the concept of 'personal testimony' was formulated. It was held that in a DNA test, the suspect does not give testimony of a personal nature as they are free to make any kind of statement or may refuse to make a statement. DNA, fingerprinting and handwriting are intrinsic to the true nature of the individual. Acquiring and retaining DNA samples are physical evidence and do not act as a barrier to constitutional rights. The court in Krishna Kumar Malik v. State of Haryana[35], it was observed that even in the exclusivity of Section 53A of CrPC, a DNA test could be permissible. But in Rohit Shekhar v. Narayna Dutt Tiwari[36], the court emphasized that an individual cannot be forced to undertake a DNA test as it would violate his right.

1. Right to Fair Trial - DNA profiling should be limited to not affect the Right to Adequate Defense and Fair Trial. This includes the right to expert services in order to forestall introduction of unreliable scientific evidence.[37] The right to adequate defense is supplemented with the right to retest as held in Barnard v. Henderson[38]. This right may be conditioned on a preliminary factor showing that results will be favorable to the defendant or that evidence is critical and subject to varying expert opinion. Reliability of technique implies test results can be reproduced when retested. Some courts reject the fact that the right to retest is due process right since the opportunity to cross-examine the prosecution's expert witness should be sufficient.[39] Instances where the right to retest is recognized, prosecution has an obligation to provide notice of its intention to use evidence to get an adequate opportunity to examine it. The use of force to obtain DNA samples can be noted as a violation to human rights and the right to privacy as under Article 3 and 8 of the ECHR, Article 17 of the ICCPR and Directive 95/46/EC.[40] Apart from the right to fair trial, DNA profiling threatens other civil rights such as - presumption of innocence, bodily autonomy, privacy, moral and physical integrity.

2. Privacy - DNA profiling holds a potential probative value and therefore is vulnerable to abuses. DNA profile holds a tissue sample detained by policy which may offer positive identification, having potential to challenge the 4th amendment's requirement of warrant. Further, it has the potential to affect the entire population due to the formulation of a databank of DNA profiles.[41] The large database of information could be used in a discriminatory manner, violating the privacy of individuals. There are 4 reasons the court may admit DNA fingerprinting irrespective of its potential of abuse: each DNA profile is unique, thereby offering a high probative value of evidence; DNA is likely to lead to the evidence sought and not search-based evidence; it is relatively nonintrusive process and DNA has characteristics displayed to the public thereby including lower privacy concerns.[42] Such procedures involve a balancing test for reasonableness weighed against the need of police for evidence against invasion of individual privacy. In the United States v. Jacobsen[43], the court highlighted that on-site testing on less than probable cause which would reveal private information would be impermissible. Privacy concerns surround vulnerable information such as unknown personal characteristics like homosexuality and religiosity along with behavioral traits. Such critical information if released, could lead to racial profiling and discrimination.[44]

The Universal Declaration on Human Genome and Human Rights includes the right to decide whether to be informed or not in furtherance to the results of the genetic examination. In S & Marper v. The UK[45], the court found a 'blanket and indiscriminate' retention of DNA which was considered disproportionate and violative of human rights. Post the decision, destruction and deletion of more than 7 million DNA samples and 1 million subject profiles was

[34] 1961 AIR 1808.
[35] 2011 AIR SC 2970.
[36] 2011 (121) DRJ 563.
[37] Porter, C., *The Forensic use of DNA,* Australian Journal of Forensic Sciences, 37(1), 5–8 (2005), https://doi.org/10.1080/00450610509410607
[38] 514 F. 2d 744, 746 (5th Cir. 1975).
[39] Update, N. R. C. (US) C. on D. F. S. A., *DNA Evidence in the Legal System*, Dc (1996), http://www.ncbi.nlm.nih.gov/books/NBK232607/
[40] Malik, M., Archana, *DNA Profiling in Forensic Science: A Review*, (2021).
[41] Roux, C., Walsh, *DNA Profiling a And Criminal Justice: A Contribution to a Changing Debate,* Australian Journal of Forensic Sciences, 36(1), 34–43 (2004), https://doi.org/10.1080/00450610409410592
[42] Freckelton, I., & Chambers, O. D., *DNA Profiling: Forensic Science under*, DNA and Criminal Justice, August, 27–47(1989).
[43] 466 U.S. 109 (1984).
[44] Wong, H. Y., Tan, J., Lim, Z. G., Kwok, R., Lim, W., & Syn, C. K. C., *DNA profiling success rates of commonly submitted crime scene items,* Forensic Science International: Genetics Supplement Series, 7(1), 597–599 (2019). https://doi.org/10.1016/j.fsigss.2019.10.104
[45] [2008] ECHR 1581.

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ordered respectively.[46] The Prüm Convention mandates reference data to be formulated for national DNA analysis files. On these lines, the UK government set up a National DNA Database in 1995 with an aim to maximize the investigation based on DNA profiles. Very few states like Netherlands, have a specific law dealing with forensic DNA phenotyping; in Germany Article 81e of the Criminal Code allows for investigation of DNA only for certain purposes i.e., to determine parentage and source link to victim.[47] Surprisingly, the USA does not have a federal legislation dealing with forensic phenotyping and disallows use of DNA submitted to data banks for determining DNA sources.

3. DNA BILL, 2018 - It has been half a decade since attempts from the side of the Indian legislature to introduce a DNA bill in the Parliament, but efforts have drastically failed. India introduced the DNA Technology (Use & Application) Regulation Bill in 2018 with an aim to enact a comprehensive framework designed to address DNA admissibility, delineated standards, quality controls and credibility of DNA testing.[48] The Bill recommends constitution of a DNA Profiling Board dealing with functions of establishment of Laboratories, its accreditation, their supervision and policy framing for investigative agencies. DNA profiling is sought to be limited to identification of the person and assisting the kith and kins of a missing person; the bill prohibits extraction of any other collateral information. In lines with the UK Database, the draft bill seeks to establish national and regional DNA Databanks.[49] The key right to retest has been envisaged in the bill to rightly protect the accused and ensure a fair trial. Further, in light of the Puttaswamy[50] judgment, the Bill aims to provide strict confidentiality with respect to storing DNA profiles. The Bill is a harbinger of hope but falls flat to some criticism. The Schedule lists civil matters along with DNA testing to be carried out in medial or research laboratories, but the Bill seems unclear r on its regulation of such laboratories. Consent per se is explicitly mentioned but the requirements of consent are not specified. The Bill offers loopholes in the form of infringement of privacy and autonomy; lack of purpose limitation and offers wide discretionary powers to the State.

VI. ANALYSIS - DARK SIDE OF DNA PROFILING

A free society is ultimately judged based on its success in promoting human rights in the backdrop of human autonomy and human capacity for growth and development. While forensic science has been a great boon, it has taken the shape of being undisputable like the law of gravity. The technology has been an easy sell where individualized justice has diminished due to the "99% or 100% certainty" the emerging technology backs. DNA profiling in the technological domain may be limitless but from the legal arena, the ability to identify criminal suspects is a bit hazy.[51] It has been often considered as unreliable scientific evidence which meets the criminal defendant. Unproven scientific techniques have caused courtrooms to turn into scientific laboratories and defendants into guinea pigs. DNA typing causes an accusatory finger to be pointed at the suspect as a consequence of a positive identification. It is impossible to achieve 'perfect' individualization, making the system reliable on probabilities rather than certainties.[52]

While the legal community did try to withhold introducing novel techniques for DNA identification, the reliability proved too tempting to refuse. With exponential growth in the late 1980s, DNA hailed as being 'foolproof' and 99% accurate.[53] The CSI effect has led to DNA assuming a role symbolic to an ideology wherein machines are more reliable than human action and knowledge; thereby leading to a perception that DNA evidence offers 'infallible evidence.'[54] The landmark case of People v.

[46] Gill, P., *Application of low copy number DNA profiling. Croatian Medical Journal*, 42(3), 229–232 (2001).
[47] Sheard, B., *DNA Profiling*, The Medico-Legal Journal, 58 (Pt 4), 189–198 (2001). https://doi.org/10.1177/002581729005800403
[48] United States Department of Justice- Office of the Attorney General, *advancing justice through DNA technology: Using DNA to solve crimes*, 1–9 (2014), https://www.justice.gov/ag/advancing-justice-through-dna-technology-using-dna-solve-crimes
[49] Linacre, A., & Templeton, J. E. L., *Forensic DNA profiling: state of the art*, Research and Reports in Forensic Medical Science, 25 (2014). https://doi.org/10.2147/rrfms.s60955
[50] (2017) 10 SCC 1.
[51] Fragments in Forensic Science, 34(1993).
[52] Academy, N., Academy, N., & States, U., *The Evaluation of Forensic DNA Evidence*, Proceedings of the National Academy of Sciences of the United States of America, Published by: National Academy of Sciences (2016), http://www.jstor.org/stable/42099.
[53] Luftig, M., & Richey, S., *DNA and forensic science*, New Eng. L. Rev., 609–613 (2000), http://heinonlinebackup.com/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/newlr35&section=34
[54] Supra note 36.

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Castro[55], became an inroad to the infallibility mystique of DNA profiling. Had the case followed the regular course of pleading guilty post the DNA evidence, the dark side would have probably not caught the light of day. The case allowed for experts to testify against the admission of DNA wherein the blunders of Life codes in conducting the test were unraveled, making the match inadmissible.

The court in Kumho Tire Co. v. Carmichel[56], refused to segregate technical testimony from scientific evidence making the former subject to rigor of the Daubert v. Merrell Dow Pharmaceuticals Inc[57]. These decisions removed the cloak of invisibility relying on technical expertise as opposed to forensic methods as the foundation of expert opinion. The current system of forensic testing and reliability on DNA is contended due to the issues in the following domains: Lack of control to ensure accurate interpretation of results, standards to declare matches, standards for determining probability of a coincidental match and determination of relevant population study, standard for record keeping, standard for choice and number of polymorphic sites to be studied, standards for proficiency testing and licensing.[58]

Inaccurate results and errors in matching could result from inherent problems in scientific laboratories such as contamination and laboratory slop. Laboratories procedures are not foolproof as a constant danger of revisiting and cross-examination between the probe and sample DNA. Contamination from the probe could result in a false positive result due to its similar band production, eventually incriminating an innocent person. In the Castro case, the company knowingly continued the use of contaminated probes, while Life codes chose to discount 2 extra bands in order to declare a match.[59] DNA band results are blur, faint and variable due to incomplete hybridization making constant variations in thickness and consistency of gels, temperatures and voltage levels. This could result in low stringency conditions of the test, leading to a laboratory slope. The Southern blot procedure has often resulted in possibilities of error as the bubbles on the nylon membrane block the transfer of DNA, making bands vanish.[60]

Problems of contamination and degradation are likely to be supplemented with a complexity in results and a potential examiner bias. Contamination has taken the form of a rule rather than an exception. For illustrative purposes, a sample collected from a carpet or clothing could contain chemicals of substances used to recently clean it, like detergents. These chemicals act as a restriction enzyme causing fragmentations. There is a high probability that the sample collected is contaminated with bacteria as in the Castro case, there was no attempt to differentiate DNA recovered from sample to be human or bacterial. On the other hand, smaller samples led to lesser molecular weight DNA making it susceptible to misleading results. In the Castro case, interpretation of the result was based on visual matching of the DNA profiles. Interpretation of result and declaring of match is frequently based on visual determination as compared to numerical codes.[61] This brings to light the fact that interpretation based on visual matching is a subjective process making an inroad for examiner's bias. To curb this bias, errors in visual matching, lane-to-lane comparison should be prohibited.

Solving the banding pattern interpretation standard would not address the second problem of a lacking scientific standard for declaring a match. Castro used an averaging method, not scientifically sound for declaring a match while it was 3 standard derivatives away.[62] The need to set a threshold for declaring a match is a policy question. Apart from this, there is no consensus on the reliable polymorphic probes and the proper database size acceptable for project statistics. Probability statistics requires the population to be mixed freely to ensure equal distribution of alleles within the population. A suggested use is the Hardy-Weinberg equation for race population but the same seems faulty as the population is not freely mixed and homogenous.[63] To calculate the allele frequencies, apart from the equation, it must be in a linkage equilibrium wherein assumption is based that alleles are found by use of one probe on a sample independent from others.

With lack of record keeping, validation and reproduction of results seem inaccurate and unreliable. Record keeping is important for maintaining the integrity of the process and crucial for being admissible in the court. The Justice Department Research reported that

[55] 38 Cal.3d 301, 211 Cal.Rptr. 719; 696 P.2d 111.
[56] 526 U.S. 137.
[57] 509 U.S. 579.
[58] Supra note 7.
[59] Supra note 11.
[60] Supra note 1.
[61] Supra note 25.
[62] Bert-Japp Koops & Maurice Schellekens, *Forensic DNA Phenotyping: Regulatory Issues*, 9 COLUM. Sci. & TECH. L. REV. 158 (2007-2008).
[63] Supra note 27.

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71.2% of the 128 labs receiving samples had mistyped the sample or reported inconclusive results.[64] These statistics highlight the lack of proficiency questioning the accredited standards for laboratories. A proficiency test conducted by California Association of Crime Laboratories revealed that each lab test did not complete 50 tests without inculpating an innocent person. The UK Biometrics Commissioner reports put forth that the DNA contributes to just 0.3% of the criminal justice outcomes in in England and Wales.[65] Excluding the gray areas of forensic in the scientific domain, concerns take step outside the laboratories and into the courtroom as well. Courts deploy 2 tests to assess the admissibility and evidentiary value of scientific evidence: Frye Test and the Relevancy Test.

1. FRYE Test- In Frye v. The United States[66], the court laid down the Frye test wherein the DNA typing context states that the court is open to decide in which field the DNA profiling technique belongs, such as generics, biology, statistics, etc. Prior to the Castro case, there were no expert witnesses for the defense to conclude a general scientific acceptance.[67] Frye contemplates the testimony of impartial experts. The problem with the test is that designating the 'particular field' in which technique belongs, deciding whether both theory and technique must be generally accepted and if the technique has been generally accepted in the relevant field.[68] Practical aspect showcases the fact that the Frye test is a means of justifying the judges' own views about the reliability of forensic techniques. Courts have misinterpreted the Frye test as seen in People v. Wesley[69], wherein the court admitted evidence on the fact that the cutting edge of forensic science encompasses as the single most important aspect in the search for truth.

2. Relevancy Test- The Federal Rules of Evidence, 1975 adopted a relevancy approach which overruled the Frye test. Rules define 'relevant evidence' as being generally admissible.[70] The relevancy test provides a lower threshold of admissibility than the Frye test as the evidence would only be subject to a relevancy type balancing test of probative weight against prejudicial effect. In the United States v. Williams[71], the court outrightly rejected the Frye test stating that merely relying on scientific aspects, courts cannot surrender to the scientists the responsibility for determining the reliability of evidence. Reliability test rests on 5 standards:[72] potential rate of error in use of technique; existence and maintenance of standards among its users; care with which technique was employed and whether technique lends itself to abuse; analogy of technique to others results are admissible; and presence of safeguards in characteristics of technique. The Williams relevancy test relies on the measure of probative value of evidence put forth; followed by a prejudicial effect.

In Andrews v. State, and Bundy v. State[73] DNA evidence was admissible without any defense witnesses. This highlights that experts testifying grossly oversimplified the technique, overly impressing the jurors leading to a follow in of the prosecution expert's explanation. In People v. Collins[74], the courts have rejected the statistical evidence as more prejudicial than probative. Use of statistics could be confusing as it brings a hazy line to decide guilt or innocence 'beyond reasonable doubt.' The attempt to quantify reasonable doubt in translation to mathematical terms often leads to odds being more prejudicial than probative. For instance: the probability, one in 10,000 would on one hand not make any difference as in real problems it would not describe what it was calculated; but on the other hand, imply that if the court's jurisdiction covers a million people, there are 100 people who have a matched probability.[75]

VII. EMPIRICAL RESEARCH

A questionnaire was prepared and circulated via google form to students across the nation. The survey received 50 respondents, who were questioned about the interplay of DNA profiling. The results of the empirical research are displayed below and based on the critical analysis seem to correlate with the existing doctrinal research.

[64] Supra note 23
[65] Supra note 50.
[66] 293 F. 1013 (D.C. Cir. 1923).
[67] Supra note 55.
[68] Supra note 45.
[69] 73 N.Y. 2d 351 (1989).
[70] Supra note 40.
[71] 553 U.S. 285 (2008).
[72] Supra note 2.
[73] 143 Ohio St.3d 237.
[74] 438 P.2d 33 (Cal. 1968).
[75] Supra note 9.

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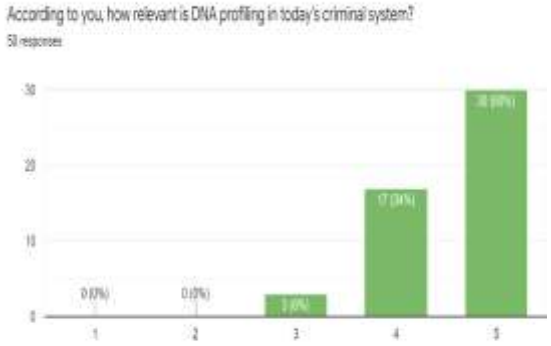

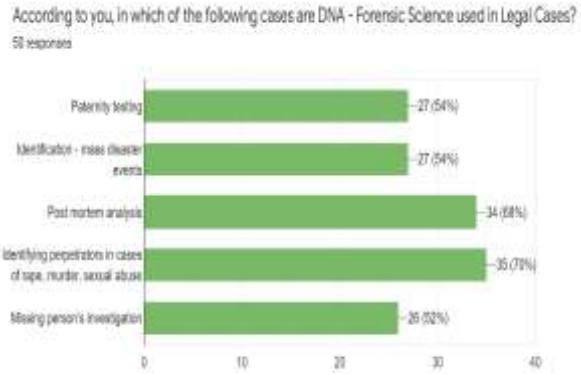

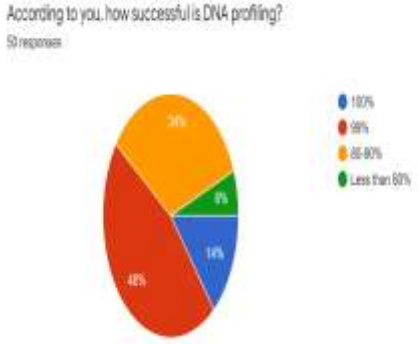

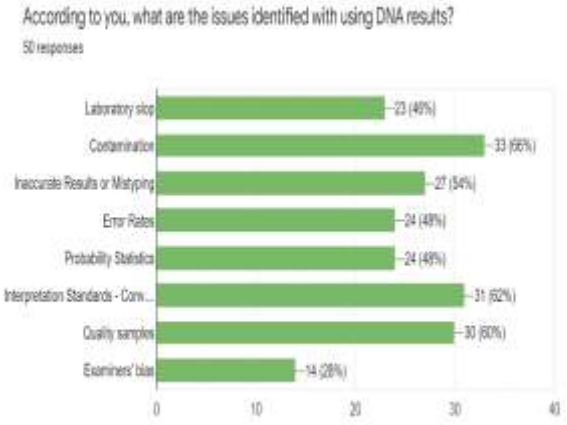

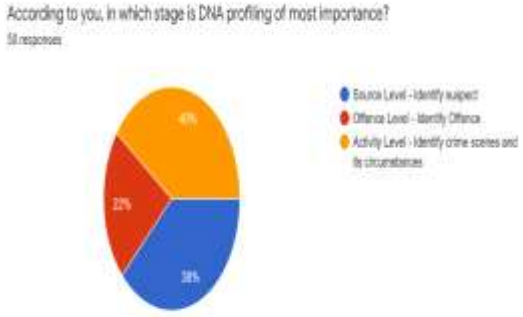

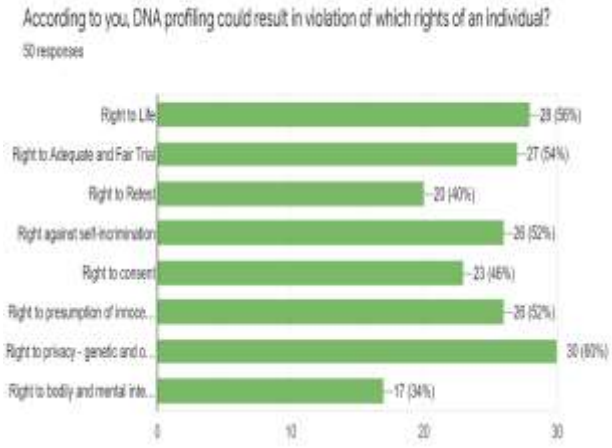

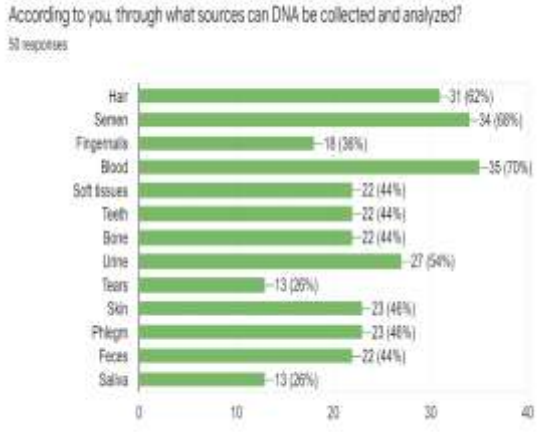

VIII. RECOMMENDATIONS

For scientific procedure to attain probative value, it must be robust, sensitive, confident and accurate. With the existing scientific void, neither the Frye test nor the relevancy test uphold the reliability of DNA profiling. The Subcommittee on Civil and Constitutional Rights recommends uniform standards to be established for upholding reliability of DNA profiling in criminal cases. Setting up an independent system for proficiency testing and

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licensing; guidelines and protocols for testing; establishing uniform standards for declaring matches; requirements for lab recording and disclosure and continued research on population frequency data could be established.[76] It can be recommended to establish an independent research ethics commission to approve research and address concern over DNA profiling and use of sensitive personal data. The Committee on DNA Technology in Forensic Science Board on Biology, 1989 highlighted the shift in focus from defense counsels' attack on admissibility, to deficiencies of technique to inadequacy of population data and estimates of random probability method.[77]

Lack of uniform standards and qualified controls enable ambiguities to creep in, making the match unreliable. Therefore, the ceiling principle should be used to calculate conservative frequencies figures from new databases while shifting from the fixed bin approach. The ceiling principle forms an international conservative method of estimating frequency with which individuals who share particular alleles appear in a general population. From a policy perspective, there should be a balance between legitimate use of databases by law enforcement in light of the privacy concerns. To keep up with the advancements in technology and balance human rights, there is a need to develop a symbiotic system. On the basis of ethical principles, recommendation to enact a framework needs to be developed which encompasses: Prevention of malign use in consistency with human rights and one's dignity; Safety precautions to be embedded; Creation of user-centered approaches; More inclusiveness and convergence; Avoiding a single central agency and creating a body to regulate with checks and balances; Formulating DNA profiling rights in its exclusive domain; Transparency and openness of process; Capacity and autonomy with public trust; Privacy and confidentiality with DNA associated data; and Defining limits of DNA law and its applicability.

The Nuffield Council on Bioethics Report indicated the use of DNA to coerce or deceive individuals with an aim to obtain a guilty plea.[78] Therefore, apart from the scientific gap and recommendations to fill it, having a legal framework is a must. India does not have a legislative backing despite its several attempts. Legitimate concerns about abrogation of privilege against self-incrimination, lack of accountability for abuse of police powers, forensic laboratories accountability, use of force in police stations, appropriateness of coercive & intrusive means, and targeting of suspected persons without reasonable doubt; must be addressed. While the recent DNA Bill, 2018 offers hope, it is yet on hold with a number of flaws. The safeguards to incorporate prevention of privacy could be elaborated. National and regional DNA Databanks could have a segregation between criminal and civil matters to ease the requirements and profiling facilities.[79] The Bill could take a stand on creating medical profiles - express prohibition or implied use, as the current Bill does not address the same. While the Bill envisages maintaining confidentiality, its authorities share information with foreign governments. To curb any misuse or human right violations, in regards to handling personal data, express provisions to prevent misuse and guidelines could be laid down.

IX. CONCLUDING REMARKS

"Forensic Science is justice's best friend, but it has to not only be used right but done right" - Richard Willing[80]

DNA profiling of humans in the criminal domain is a gold standard due to its high evidentiary value. Initially, courts admitted forensic DNA evidence based on uncontested claims by interested labs that their procedures were reliable and accepted. Forensic evidence is considered the hallmarks of certainty that the legal fraternity craves for and it would be a miscarriage to justice if a person is not allowed to put up a defense on the sheer match of DNA probabilities. The growing advancements in technology, calls for the scientific community to reform and review the DNA profiling technique in lines to uniform standards to ensure accuracy and reliability. With the shift from mechanical jurisprudence to jurimetrics, one must ensure the gap is bridged between judges, prosecutors, scientific experts and laboratories to ensure mathematical accuracy is maintained in the courtrooms in a socio-legal context.[81] Absolute individualization is a theoretical goal and inclusion of more markers in DNA increases the likelihood of a profile match. Experience and lessons must be drawn from the Castro case, putting a curb on the enthusiasm for scientific advances to overshadow the concept of fairness

[76] Supra note 10.
[77] Supra note 5.
[78] Supra note 16.
[79] Supra note 23.
[80] Supra note 68.
[81] Supra note 56.

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and justice. Forensic science does aim to bridge the confidence gap by addressing the existing concerns and sealing the defendant's fate but as of today the public crime laboratories cannot be considered the sanctuaries of science we uphold.