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ADMISSIBILITY OF FORENSIC EVIDENCE IN INDIA: A COMPARATIVE ANALYSIS WITH USA

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Abstract: *The Admissibility of Forensic Evidence is critical to both legal systems, while having a stark potential to impact parties' rights and ongoing court proceedings in India and the United States. This research analyses admissibility standards and practices around forensic evidence in these systems, focusing on the ramifications of the difference in legal regimes. The study discusses how differences in systems cause differences in degrees of admissibility, credibility and acceptability of forensic evidence in the criminal justice processes. It discussed evidence, law, and standards of admissibility (Frye and Daubert in the USA), as well as the evolution of law in India to similar standards through influential cases. The methodology is mixed methods and combines qualitative and quantitative methods, comparative analysis of legal standards, practices and protocols, qualitative data and evidence synthesis from literature and case law. The research sets out the history of forensic practices in both legal frameworks, examines problems with forensic evidence practices, including contamination, bias and technological advances in forensic practice, and considers the scope of the judicial process and outcomes. This research assesses whether the challenges identified impede effective forensic practice, where baseline standards have not been confirmed, and assesses recommendations for standardising relevant forensic practices. The comparative legal analysis provides strong evidence to support litigation for improved forensic standards and protocols. The findings support an evidence-based viewpoint that forensic science can enhance judicial quality and improve public confidence in justice. Ultimately, this represents an increase in evidence-based judgments that form the basis for attaining credibility and trust in the legal system.*

Keywords: Forensic Evidence, Admissibility, Comparative Analysis, India, USA

INTRODUCTION

Background and significance of forensic evidence in criminal justice

The role of forensic evidence in crime investigation and the legal system is vital because it uses a scientific approach to understand criminal activities and the relationship between suspects and crime. Forensic evidence is generally used in many scientific fields, such as forensic biology, toxicology, and digital forensics[1].Each aspect of the forensic sciences contributes something different to the legal process. Forensic evidence allows the justice system to examine empirical evidence to describe the circumstances surrounding crimes and assess whether someone is culpable based on this unbiased and objective evidence[2].

Forensic science is valuable; however, one important aspect of forensic science is the reliability and objectivity of evidence. When techniques such as DNA profiling were introduced as a sub-discipline of forensic science, forensic science could say there is evidence of a comparison between a piece of evidence associated with a crime scene and the genetic composition of a suspect. This method allows law enforcement to exclude or confirm linkage between a suspect and evidence associated with a crime with great accuracy[3]The usefulness of forensic evidence goes beyond the investigative phase. It extends to the courts, where it can potentially influence jurors' or judges' decisions based on scientific fact.[4] Evidence used in a legal setting must be admissible to be valued. Admissibility is essentially considered to be topics focused on

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[1] Meynen G, 'Walls and Laws: Structural Barriers to Forensic Psychiatric Research' (2017) 44 European Psychiatry 208 https://doi.org/10.1016/j.eurpsy.2017.04.010

[2] Lewulis P, 'Digital Forensic Standards and Digital Evidence in Polish Criminal Proceedings: An Updated Definition of Digital Evidence in Forensic Science' (2021) 13(4) International Journal of Electronic Security and Digital Forensics 403 https://doi.org/10.1504/ijesdf.2021.116024

[3] Irmansah I, Satria H and Dagani G, 'Proof of the Crime of Murder Regardless of the Use of Forensic Autopsy Evidence (Kendari District Court Study)' (2024) 14(1) Dusturiyah: Jurnal Hukum Islam Perundang-Undangan dan Pranata Sosial 64 https://doi.org/10.22373/dusturiyah.v14i1.23289

[4] Zawoad S and Hasan R, 'FAIoT: Towards Building a Forensics Aware Ecosystem for the Internet of Things' (2015) *Proceedings of the 2015 IEEE International Conference on Services Computing (SCC)* https://doi.org/10.1109/scc.2015.46

NFSU JOURNAL OF FORENSIC JUSTICE

JFJ
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congruence with no science but usually restricted and researched under criteria established by the Frye and Daubert systems, where admissible forensic evidence goes through phase testing requirements to ensure the methodology of admissible evidence, regardless of considering the opposite outcomes[5].

Nonetheless, for all the accomplishments of forensic science, there are still numerous issues with forensic science that compromise its reliability or validity. As pointed out by O'Brien et al. (2015), current challenges include ongoing changes to crime, for example, cybercrime, and systemic omissions and absences, including a lack of resources and training across jurisdictions, "Mobile Network Architecture", 2018. Similarly, the knowledge gap between science and law obstructs the ability to present credible scientific evidence at trial[6]. For example, in forensics, a 'well-established' scientific discipline such as fingerprint analysis is now under significant review for inconsistency in reliability that resulted in wrongful convictions based on error ", Forensic Evidence Review", 2024.

Not only does the inclusion of forensic evidence support investigation and prosecution policies within the criminal justice process, but it is also valuable where the rights of victims ought to be taken into account. Only through accurately considering and documenting forensic evidence collected in domestic violence offences could potential defences be incrementally possible, especially when empowering victims through evidence collection[7]. This takes on greater importance in considering harmful social consequences on victims when the energy vested in victim support may be significantly reduced when facts surrounding a conviction are clear in the forensic data.

Furthermore, forensic science disciplines and methodologies are only improving based on the availability of new technological tools to improve evidence analysis or collection[8]. New techniques now available in forensics, such as memory forensics linked with digital tracking advances, the capabilities for investigators to obtain detailed developmental evidence across multiple digital platforms that are increasingly no longer stagnant[9]. Accepting emergent categories of forensic assessments better informs and provides rich perspectives for solving crimes where evidence of fact is vital and critical for restoring justice.

Context of Forensic Evidence in Legal Systems

The rapid rise in cybercrime has necessitated advancements in digital forensic technologies, particularly in digital evidence and its legal implications. Updates and innovations in these forensic tools are critical, as sophisticated criminal practices constantly test the integrity of digital evidence[10]. Recent research shows that when blockchain technology is added to the digital forensic evidence, the reliability and integrity of the evidence can significantly improve, specifically regarding the chain of custody and tampering[11].

Comparing the legal frameworks for forensic evidence in India and the United States helps explore relevant differences based on historical and cultural contexts. In the U.S., the Frye and Daubert Standards influence the court's admissibility of forensic evidence. The Frye Standard states that scientific evidence does have "general acceptance" in the relevant community[12], a concept from 1923. The Daubert Standard initiated this concept in a new direction, considering testability, peer review, error rates, etc., as the basis for judges to decide on the reliability of forensic evidence in a case. This occurred in 199 in this case, judges

[5] Adam C, Forensic Evidence in Court (2016) https://doi.org/10.1002/9781119054443

[6] Arab F, Abdullah S, Hashim S, Manaf A and Zamani M, 'A Robust Video Watermarking Technique for the Tamper Detection of Surveillance Systems' (2015) 75(18) *Multimedia Tools and Applications* 10855 https://doi.org/10.1007/s11042-015-2800-5

[7] Wyatt D, 'Practising Crime Scene Investigation: Trace and Contamination in Routine Work' (2013) 24(4) Policing & Society 443 https://doi.org/10.1080/10439463.2013.868460

[8] Snigerov O and Andrenko S, 'About Concept Definition of Forensic Science in Administrative Proceedings' (2018) 18 Theory and Practice of Forensic Science and Criminalistics 231 https://doi.org/10.32353/khrife.2018.25

[9] Alaeva G and Kabdoldina Y, 'Use of Digital Technologies in Forensic Expertise in Kazakhstan and Worldwide: Prospects and Challenges' (2025) 1(10) Eura https://doi.org/10.46914/2959-4197-2025-1-1-38-47

[10] Brunty J, 'Validation of Forensic Tools and Methods: A Primer for the Digital Forensics Examiner' (2022) 5(2) Wiley Interdisciplinary Reviews: Forensic Science https://doi.org/10.1002/wfs2.1474

[11] Naqvi S, Sommer P and Josephs M, 'A Research-Led Practice-Driven Digital Forensic Curriculum to Train Next Generation of Cyber Firefighters' (2019) *Proceedings of the 2019 IEEE Global Engineering Education Conference (EDUCON)* 1204 https://doi.org/10.1109/educon.2019.8725129

[12] Pergolizzi J and LeQuang J, 'Black Robes and White Coats: Daubert Standard and Medical and Legal Considerations for Medical Expert Witnesses' (2024) Cureus https://doi.org/10.7759/cureus.69346

NFSU JOURNAL OF FORENSIC JUSTICE

JFJ
Volume: 4, Issue: 2
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are gatekeepers of what counts as reliable scientific information in court[13]. Furthermore, the Federal Rules of Evidence also add value to the reliability standards for expert testimony, especially with Rule 702, to form a strong link between the laws, scientific principles, and facts[14].

On the other hand, the legal framework regarding forensic evidence in India is grounded in the Indian Evidence Act of 1872, which does not provide any particular standards for admissibility that suit forensic evidence like those in the U.S. The absence of applicable standards causes programs applying forensic evidence in Indian courts to use varying degrees of evidence[15]. Although landmark cases have acknowledged the importance of forensic tools, such as DNA evidence and even toxicology reports, the inconsistency in judicial acceptance illustrates a greater necessity for meaningful legal frameworks to acknowledge modern forensic evidence[16]. The acceptance of forensic evidence demonstrates the influence that forensic evidence can have on a case outcome. A notable challenge for both legal systems is the education and training of forensic professionals. In the United States, rigorous training and certification ensure that forensic experts adhere to best practices, fostering a culture of empirical testing and peer review[17]. Conversely, the training of forensic professionals in India is often insufficient, which creates a disparity between technological advancements and their practical application in legal contexts[18]. The lack of standardised training protocols can undermine the credibility of forensic evidence, leading to varying interpretations and judgments among judicial authorities. As the need for skilled digital forensic professionals intensifies, addressing this skills gap is critical for enhancing the effectiveness of forensic investigations[19].

Moreover, the issues of cognitive bias and its impact on forensic decision-making cannot be overlooked. Research indicates that forensic scientists and legal practitioners must understand the constraints imposed by cognitive biases on their judgments, as these can influence case outcomes[20]. In the U.S., an increasing body of literature calls for improved practices to mitigate these biases within forensic science[21]. Similarly, Indian courts may need to incorporate awareness of such psychological factors to enable a more informed and accurate evaluation of forensic evidence[22].

The ongoing development of digital forensics represents another area of focus for both countries. While the U.S. has established detailed protocols for the admissibility of digital evidence, India's evolution in this domain significantly lags behind[23]. As cyber threats continue to evolve, both nations must establish legal frameworks capable of accommodating emerging technologies and ensuring that forensic evidence is evaluated consistently and reliably[24]. The inconsistencies currently observed in India's judicial handling of digital forensic evidence highlight the importance of establishing clearer guidelines and standard operating procedures[25].

[13] DiMaggio J and Vernon W, '10 Frye Test and Daubert Standard' in *Digital Forensics for Network, Internet, and Cloud Computing* (2017) 265 https://doi.org/10.1201/9781315395029-11

[14] O'Brien C, Popovic K and Fitzgerald R, 'Science in the Court: Pitfalls, Challenges and Solutions' (2015) 370 Philosophical Transactions of the Royal Society B: Biological Sciences https://doi.org/10.1098/rstb.2015.0062

[15] Baryah N, Krishan K and Kanchan T, 'The Development and Status of Forensic Anthropology in India: A Review of the Literature and Future Directions' (2019) 59(1) Medicine, Science and the Law 61 https://doi.org/10.1177/0025802418824834

[16] Vaswani, V. and Ahmed, M. (2019). Forensic anthropology education and training in india. Medicine Science and the Law, 60(1), 83-84. https://doi.org/10.1177/0025802419879003

[17] Keierleber J and Bohan T, 'Ten Years After Daubert: The Status of the States' (2005) 50(5) Journal of Forensic Sciences JFS2004241-10 https://doi.org/10.1520/jfs2004241

[18] Baryah N, Krishan K and Kanchan T, 'The Development and Status of Forensic Anthropology in India: A Review of the Literature and Future Directions' (2019) 59(1) Medicine, Science and the Law 61 https://doi.org/10.1177/0025802418824834

[19] Naqvi S, Sommer P and Josephs M, 'A Research-Led Practice-Driven Digital Forensic Curriculum to Train Next Generation of Cyber Firefighters' (2019) *Proceedings of the 2019 IEEE Global Engineering Education Conference (EDUCON)* 1204 https://doi.org/10.1109/educon.2019.8725129

[20] Mahamid F, Berte D and Salameh N, 'Establishing Applied Forensic Psychology in Palestine: Legal and Psychological Issues' (2022) 6(2) Journal of Mental Health and Clinical Psychology 22 https://doi.org/10.29245/2578-2959/2022/2.1254

[21] O'Brien C, Popovic K and Fitzgerald R, 'Science in the Court: Pitfalls, Challenges and Solutions' (2015) 370 Philosophical Transactions of the Royal Society B: Biological Sciences https://doi.org/10.1098/rstb.2015.0062

[22] Brunty J, 'Validation of Forensic Tools and Methods: A Primer for the Digital Forensics Examiner' (2022) 5(2) Wiley Interdisciplinary Reviews: Forensic Science https://doi.org/10.1002/wfs2.1474

[23] Mahamid , supra note 20

[24] Baryah , supra note 18

[25] Vaswani V and Ahmed M, 'Forensic Anthropology Education and Training in India' (2019) 60(1) Medicine, Science and the Law 83 https://doi.org/10.1177/0025802419879003

The implications of these disparities are profound, as the reliability and acceptance of forensic evidence vary significantly between the two legal systems. The American judicial system's confidence in DNA evidence and the rigorous analytical practices surrounding it demonstrate the potential for forensic science to secure convictions[26]. Meanwhile, in India, the understanding and application of forensic evidence remain outdated, which can lead to wrongful convictions or acquittals due to inadequate scientific evaluation[27].

RESEARCH QUESTIONS

1. What are the differences in the admissibility criteria of forensic evidence in India and the USA?
2. How do these differences impact the legal proceedings in each country?
3. What can India learn from the USA to improve its forensic standards?

THE HISTORICAL CONTEXT

The admissibility of forensic evidence in the United States has changed considerably throughout legal history. Lawyers have debated the importance of respecting the accuracy of scientific testimony versus the rights of the individuals involved in criminal legal proceedings. The Frye Standard and Daubert Standard are central to this debate and demonstrate the procedural standards for forensic evidence. The Frye Standard, an outgrowth of the 1923 case Frye v. United States, states that expert testimony based on scientific principles is admissible only when the methodology in question has gained "general acceptance" in the relevant scientific community. This standard was created in direct response to scepticism about the reliability of the polygraph testing since it lacked empirical reliability. The Frye Standard is used as a measure of scientific reliability through community belief, which better protects jurors from relying on speculation due to a lack of backing by the scientific community.[28].

However, criticism regarding the Frye Standard has developed because forensic science has dramatically advanced. Critics are concerned that solving the admissibility of new scientific techniques (if relevant) would be exclusive to the "general acceptance" test. This allowed for discussions on developing legal frameworks and what reform might look like. For example, the National Research Council expressed concerns regarding the roles of the judicial system as a gatekeeper, noting that many forensic techniques were presented to juries with relatively little validation[29]. This criticism highlighted the failure of the Frye Standard to create good practices that benchmark scientific development and maintain evidentiary authenticity. Further, the Frye Standard has conflicting effects across jurisdictions, with some states, such as California and New York, adopting the Frye Standard, and some retaining their admissibility criteria[30]. As development in forensic science continued, it is evident that the changes in forensic science necessitated a more flexible admissibility standard, which led to the Daubert Standard.

The Daubert Standard came from Daubert v. Merrell Dow Pharmaceuticals (1993) and established a more articulated approach to evaluating the admissibility of expert testimony in federal courts. The Daubert Standard imposed the "gatekeeping" duty of judges to evaluate general scientific acceptance but also included judges' need to evaluate relevance and reliability for admissibility based on a list of actions, including the testability, error rate, and operating procedure.[31]

The Daubert Standard changed the paradigm, emphasising empirical testing and applying methodology, instead of just community acceptance Edmond, 2019. This has established a wider range of expert testimony deemed admissible, developed new practices in forensic science, and expanded the admissibility of

[26] Brunty J, 'Validation of Forensic Tools and Methods: A Primer for the Digital Forensics Examiner' (2022) 5(2) Wiley Interdisciplinary Reviews: Forensic Science https://doi.org/10.1002/wfs2.1474

[27] Baryah N, Krishan K and Kanchan T, 'The Development and Status of Forensic Anthropology in India: A Review of the Literature and Future Directions' (2019) 59(1) Medicine, Science and the Law 61 https://doi.org/10.1177/0025802418824834

[28] Thompson W, 'Legal Standards for the Admissibility of Expert Testimony: Implications of the 2009 National Research Council Report on Forensic Sciences' (2011) 130(4_Supplement) The Journal of the Acoustical Society of America 2518 https://doi.org/10.1121/1.3655041

[29] Thompson W, 'Legal Standards for the Admissibility of Expert Testimony: Implications of the 2009 National Research Council Report on Forensic Sciences' (2011) 130(4_Supplement) The Journal of the Acoustical Society of America 2518 https://doi.org/10.1121/1.3655041

[30] Ibid

[31] McKay J, Martín M, Ascolese M and DiEmma G, 'North Carolina State University and the Forensic Technology Center of Excellence Two-Part Virtual Workshop Series: Qualifications of an Expert Witness for Legal Professionals—The Daubert and Frye Standards' (2023) https://doi.org/10.3768/rtipress.2023.cp.0017.2312

JFJ
Volume: 4, Issue: 2
July-December 2025
E-ISSN: 2584 - 0924

evidence. The Daubert Standard provides a better alignment of legal evidentiary standards to the relative instability of forensic science, ultimately leading to expert testimony in courtrooms that can be perceived as more reliable.[32]

Also, an advantage of the Daubert standard is that it provides sufficient leeway for some form of consideration of new and under-researched scientific methods, which may not be commonly accepted, but still establish a reliability baseline. This leeway continues to be especially relevant considering the incorporation of new forensic science technology, which relies heavily on artificial intelligence and computational methods. The subject and discussion, however, is intensified by a call for a strong regulatory framework that protects the sanctity of evidentiary value despite the new scientific epistemologies emerging in forensic science, alongside experts advocating for an understanding of AI as a necessary component to be incorporated into presenting forensic evidence[33].

ADMISSIBILITY OF FORENSIC EVIDENCE IN INDIA

Evolution of Indian Law on Forensic Evidence

The evolution of Indian law regarding forensic evidence is a complex development that will largely determine technological advancements, judicial decisions, and legislative changes. Forensic evidence has typically not been conclusive in India, mainly due to the lack of dependable or scientific validation and expert opinion. The arrival of modern forensic science, particularly DNA analysis, has drastically changed perceptions. The robustness of DNA as evidence was recognised as a potent instrument to verify, in court, the identities of the guilty or innocent[34]Because of DNA, legislators and courts have been considering ways to reframe the frameworks for forensic evidence in criminal cases.

The legal basis for admitting forensic evidence is primarily derived from the Indian Evidence Act of 1872, which was a "product of its time," and therefore "did not capture the importance of scientific advancements in forensic science"[35]. Over time, important cases have been shaping how the admissibility of forensic evidence develops towards more evidence. The introduction of the need for a proper chain of custody for physical evidence allows the courts to appropriately respond when the police provide evidence about a seized item(s) that could not be relied upon[36]. Technology has also created the opportunity for the legislators and judicial officers to update the law to accept new forms of digital forensic evidence, thus embodying a responsive legal system[37].

Scholars and researchers recommend systemic guidelines and norms to measure the progress of forensic science. This is essential given the assortment of forensic practices and possible variance in results based on methodologies[38]. The need for a system that evaluates the quality of forensic evidence while providing an accurate integration of expert opinions into the legal system illustrates the growing acceptance of the value of forensic evidence in judicial proceedings[39].

Landmark Cases and Judicial Directions

Several landmark cases have directly impacted the admissibility of forensic evidence in India. A key case is the State of U.P. v. Ram Babu Mishra.[40]The Supreme Court accepted DNA profiling as evidence of fact, stating that DNA profiling standards upheld evidence with more reliability and validity than other forensic tests,

[32] Ibid

[33] Ravesangar K, Raghav R, Raghav A and Jain A, 'Bridging Forensic Science, Legal Standards, and Artificial Intelligence' (2025) 43 https://doi.org/10.4018/979-8-3693-9405-2.ch003

[34] Srivastava A, Harshey A, Das T, Kumar A, Yadav M and Shrivastava P, 'Impact of DNA Evidence in Criminal Justice System: Indian Legislative Perspectives' (2022) 12(1) Egyptian Journal of Forensic Sciences https://doi.org/10.1186/s41935-022-00309-y

[35] Lohani A and Abbas A, 'An Appraisal of Cases Under Section 9(c) of the Control of Narcotic Substance Act 1997 and the Role of Forensic Evidence' (2022) VII(II) Global Legal Studies Review 16 https://doi.org/10.31703/glsr.2022(vii-ii).02

[36] D'Anna T, Puntarello M, Cannella G, Scalzo G, Buscemi R, Zerbo S, et al, 'The Chain of Custody in the Era of Modern Forensics: From the Classic Procedures for Gathering Evidence to the New Challenges Related to Digital Data' (2023) 11(5) *Healthcare* 634 https://doi.org/10.3390/healthcare11050634

[37] Franț A, 'Forensic Challenges Regarding the Internet of Things' (2023) 177 SHS Web of Conferences 03002 https://doi.org/10.1051/shsconf/202317703002

[38] Meilia P, Freeman M and Zeegers M, 'A Review of the Diversity in Taxonomy, Definitions, Scope, and Roles in Forensic Medicine: Implications for Evidence-Based Practice' (2018) 14(4) Forensic Science, Medicine and Pathology 460 https://doi.org/10.1007/s12024-018-0031-6

[39] Villavicencio-Queijeiro A, Loyzance C, Castillo Z, Hernández L, Castillo-Alanís L, Olvera C, et al, 'Development of an Instrument for Assessing the Quality of Forensic Evidence and Expert Testimony from Three Feature-Comparison Methods: DNA, Voice, and Fingerprint Analysis' (2021) 67(1) *Journal of Forensic Sciences* 217 https://doi.org/10.1111/1556-4029.14898

[40] State of Uttar Pradesh v Ram Babu Misra AIR 1980 SC 791, (1980) 2 SCC 343

JFJ
Volume: 4, Issue: 2
July-December 2025
E-ISSN: 2584 - 0924

in Madhubala v State of M.P.[41] The court reiterated the need for strict adherence to standard operating procedures regarding DNA evidence collection and analysis, which should be conducive to the evidence being presented, to avoid questions relating to credibility and reliability at trial.[42]

Similarly, judicial directions evolved recognition for expert testimony where an expert had to use protocols based on international scientific standards. These standards preserve evidence integrity and help protect the accused's right not to be deprived of justice if the legal system does not adhere to procedure. A significant portion of judicial directiveness has been directed at ensuring forensic professionals collaborate when conducting an investigation, noting that investigations often have interactions and specialists may address more than the analytical aspects of a forensic examination[43]. Additionally, the courts acknowledged that jurors must have sufficient knowledge of forensic evidence and its application to the case[44]. It was pointed out that the capabilities of laypeople to interpret forensic information have a considerable impact on their understanding and appraisal of the forensic evidence presented to them, which also influences their verdicts to a similar degree as an expert witness would. Therefore, the study encouraged educational programs aimed at circulators and jurors on forensic practices, especially in complex situations involving forensic analysis, to better facilitate knowledge and understanding while minimising some of the misunderstandings commonly held by those in the hearing process.

Current Legal Benchmarks and Standards

There is a movement toward recognising established standards in India about forensic evidence admissibility. Forensic evidence has been viewed as becoming a valuable piece in the judicial process, especially since standards were put in place to recognise that stricter standards should be applied based on the degree to which evidence is admissible, in particular DNA evidence[45]. DNA technology is now viewed as an important part of the investigative process. It has been referred to when discussing the proposed National DNA Database Bill, concerning issues raised about wrongful convictions and the identification of offenders[46].

There is a clear need for guidelines covering a variety of forensic sources and evidence forms. The challenges are evident, as forensic practitioners have no universally accepted protocol to follow. Guidelines exist, but the understanding, use and application can vary greatly depending upon jurisdiction, indicating a need for standardised guidelines to be implemented and adhered to[47], the inconsistencies significantly impact the courts' confidence in scientific evidence that calls for a version of forensic science where processes are consistent with legal definitions[48]. The further developments in digital forensics raise new concerns that also need to be regulated regarding the processes involved in collecting and preserving evidence. The growth of digital technologies now warrants the development of these protocols to determine admissibility of digital evidence so that any digital evidence can be presented in court,[49] and at the same time the legal standards must adapt to the methods without losing civil liberties, or the ability to pursue justice.

Finally, the ongoing discussions of forensic evidence in India mark a significant and slow transition from disbelief and mistrust, before acceptance and reliance on the law profession has led to calls for reform and alignment of legal

[41] Smt Madhubala v State of Madhya Pradesh [2024] MCRC 50774/2024 (MPHC) (Dec 3, 2024)

[42] O'Brien C, Popovic K and Fitzgerald R, 'Science in the Court: Pitfalls, Challenges and Solutions' (2015) 370 Philosophical Transactions of the Royal Society B: Biological Sciences https://doi.org/10.1098/rstb.2015.0062

[43] D'Anna T, Puntarello M, Cannella G, Scalzo G, Buscemi R, Zerbo S, and Argo A, 'The Chain of Custody in the Era of Modern Forensics: From the Classic Procedures for Gathering Evidence to the New Challenges Related to Digital Data' (2023) 11(5) Healthcare 634 https://doi.org/10.3390/healthcare11050634

[44] Eastwood J and Caldwell J, 'Educating Jurors About Forensic Evidence: Using an Expert Witness and Judicial Instructions to Mitigate the Impact of Invalid Forensic Science Testimony' (2015) 60(6) Journal of Forensic Sciences 1523 https://doi.org/10.1111/1556-4029.12832

[45] Srivastava A, Harshey A, Das T, Kumar A, Yadav M and Shrivastava P, 'Impact of DNA Evidence in Criminal Justice System: Indian Legislative Perspectives' (2022) 12(1) Egyptian Journal of Forensic Sciences https://doi.org/10.1186/s41935-022-00309-y

[46] Kumar S, Verma A, Singh P and Singh R, 'Current Scenario of Forensic DNA Databases in or Outside India and Their Relative Risk' (2016) 6(1) Egyptian Journal of Forensic Sciences 1 https://doi.org/10.1016/j.ejfs.2015.03.002

[47] Magalhães T, Dinis-Oliveira R, Silva B, Gonçalves F and Vieira D, 'Biological Evidence Management for DNA Analysis in Cases of Sexual Assault' (2015) 2015(1) The Scientific World Journal https://doi.org/10.1155/2015/365674

[48] Srivastava, supra note , 45

[49] Franț A, 'Forensic Challenges Regarding the Internet of Things' (2023) 177 SHS Web of Conferences 03002 https://doi.org/10.1051/shsconf/202317703002

standards to best practices of forensic science[50]. Legislation must also be grounded on sound science, and we advocate for the consideration of legislation to contribute toward optimising public confidence in the legal and forensic practices undertaken by the judicial system.

METHODOLOGICAL APPROACHES AND PRACTICES

Forensic Methods and Technological Innovations

Forensic science is in constant flux both on and offline and is influenced by the traditional blend of good practices with new technological innovation. Forensic science is in a transitional phase, and the methods employed may range from traditional methods to the latest technological methods as introduced by digital technology. The rise of better digital forensic software in the digital forensic evolution is important, as digital forensic updates enable investigators to utilise better techniques to collect, analyse, and present digital evidence in court proceedings[51]. The end product is increased reliability and authenticity of evidence when applying some emerging technologies and updates to forensic methods, according to the path of law moving toward science.

One notable component of modern forensic science is its reliance on updated digital forensics methodologies, which have become crucial when confronting cybercrime. Jayasekara and Abeysekara discuss that digital forensics constantly changes to keep up with evolving cyber laws. As such, best practices need to continuously change to adapt to the ever-changing methodologies in modern law[52]. Best practices ensure all methodologies utilised when identifying, preserving, collecting, and analysing digital evidence have Standard Operating Procedures (SOPS), when following SOPS[53]. A methodological framework finds best practice procedures for digital evidence admissible in court, adhering to legal standards.

Furthermore, the growing pluralism of methodologies in forensic science can be observed in the tradition of wildlife forensic analysis, and similar advanced applications, such as DNA barcoding, are making strides in the field, according to Kumar et al. DNA barcoding is a key technology for identifying animal species, which has ramifications for wildlife law enforcement in India[54]. This suggests that methodologies can shift across boundaries using biological science to support legal enforcement of wildlife conservation matters.

More importantly, the emphasis on developing evidence-based forensic education illustrates the support from methodological frameworks to support the development of forensic professionals. Nilendu claims that partnerships from forensic institutions in India with those close by have significantly enhanced the curriculum and helped to establish an evidence-based education[55]. This has provided educational improvement for aspiring forensic scientists in the complexity of forensic work and enhances the range of applications of differing methodologies. In addition, forensic methodologies emerging with accounting practices have developed with the complexities of financial fraud, particularly in a regulatory environment that the recent corporate governance challenges have influence, outline the importance of forensic accounting for fraud prevention and detection, and identify the need for more awareness and development of forensic methodologies from accounting practitioners. This highlights the need for interdisciplinary methodologies that combine accounting concepts with forensic evidence gathering and analysis to better combat fraud.

In environmental forensic science, the methodologies assign geology forensic analyses to natural disasters, showing methods of clear operational pathways. Ghosh et al. outlined the forensic examination of the Chamoli Glacial Burst, where methodologies demonstrate

[50] Lesciotto K and Christensen A, 'The Over-Citation of Daubert in Forensic Anthropology' (2023) 69(1) *Journal of Forensic Sciences* 9 https://doi.org/10.1111/1556-4029.15409

[51] Leonetti C, 'Ensuring the Reliability of Evidence in the New Zealand Criminal Courts: The Admissibility of Forensic Science' (2024) 53(4) Common Law World Review 197 https://doi.org/10.1177/14737795241237799

[52] Jayasekara S and Abeysekara I, 'Digital Forensics and Evolving Cyber Law: Case of BIMSTEC Countries' (2019) 22(4) Journal of Money Laundering Control 744 https://doi.org/10.1108/jmlc-02-2019-0019

[53] Kallil M and Yaacob A, 'The Integration of Digital Forensics Science and Islamic Evidence Laws' (2019) 4(17) International Journal of Law Government and Communication 61 https://doi.org/10.35631/ijlgc.417006

[54] Kumar V, Shukla M, Rajpoot A, Thakur M, Nigam P, Kumar D, and Goyal S, 'DNA Barcoding as a Tool for Robust Identification of Cervids of India and Its Utility in Wildlife Forensics' (2018) 3(1) Mitochondrial DNA Part B 250 https://doi.org/10.1080/23802359.2018.1438858

[55] Nilendu D, 'Enhancing Forensic Education: Exploring the Importance and Implementation of Evidence-Based Education System' (2024) 14(1) Egyptian Journal of Forensic Sciences https://doi.org/10.1186/s41935-023-00375-w

delivery to create an understanding of the causes of the disaster and the extent of vulnerabilities over several dimensions, which signifies the cross-disciplinary characteristic of forensic methodologies in practical settings.[56]. This demonstrates how forensic science is developing, not only as a direct response to crime but also as a means of addressing broader issues of society and calling for different methodologies to be tailored to specifics.

Advances in technological methodologies could also be considered in data analytics, such as forensic methodologies, which identify sophisticated data analytics in seeking indications of fraudulent activities or anomalies in financial transactions. Kanhere and Khanuja draw attention to the innovative outlier detection methods to find and assess unusual activity in the financial data, to allow for timely detection of fraudulent activities, whilst improvements in accountability within financial transactions[57]. This not only reflects the contextual nature of forensic methodologies but also offers relevant insights into the understanding that the data crisis requires developments in technology and the processes of methodology in the potential further expansion of data and contexts.

HURDLES ENCOUNTERED

Forensic practices encounter significant challenges that ultimately compromise the reliability and validity of the investigative processes. Major issues include contamination, cognitive bias, and technology limitations. each of these issues is serious enough to account for errors in forensic output. These issues must be considered to maintain the unquestionable value of forensic evidence, which is the foundation of many criminal investigations and criminal court trials. Contamination is a significant threat to the integrity of forensic evidence, especially in DNA analysis. Developing molecular biology techniques, including polymerase chain reaction (PCR), has improved DNA detection sensitivity and allows analysis with only trace amounts of biological materials[58]. The increased sensitivity has also intensified the risks of contamination, since contamination can derive from only minute amounts of foreign DNA to compromise results[59]. As both Rudin and Bini have pointed out, contamination in forensic biology can be introduced at many stages in the investigation, from sampling to laboratory operation, which calls for and highlights the need for a stringent set of practices to minimise risk[60] . Introducing human DNA to forensic buildings and external environmental contaminants in the facilities exposes systemic weaknesses that are magnified during public health crises, such as the COVID-19 pandemic[61].

Several studies stress the sensitivity of forensic samples to contamination as well. For example, the product of forensic evidence can also be made complex by contact with surrounding biological materials due to possible cross-contamination[62]. The issue of specificity also applies to other forensic methods that use DNA, because if multiple sources of DNA contribute trace amounts, it can be hard to differentiate between subjective genetic markers[63]. Additionally, even managing or unwittingly mixing samples in forensic science labs can induce cross-contamination, which reduces the evidential value of kinship analysis[64].

Bias entrenchment in forensic practices is the last central point of contention. Forensic practitioners and all individuals risk cognitive bias affecting evidence interpretation, case management, and decision-making. The different types of bias, including confirmation and contextual bias, can prevent analysts from reasoning objectively and scientifically, as forensic evidence analysis assumes[65]. As a result

[56] Ghosh P, Bout B, Westen C and Atún F, 'Chamoli Glacial Burst: Investigating the Vulnerability of the Himalayan Geology with the Support of Forensic Analysis' (2025) https://doi.org/10.5194/egusphere-egu25-20476

[57] Kanhere P and Khanuja H, 'A Methodology for Outlier Detection in Audit Logs for Financial Transactions' (2015) 837–40 https://doi.org/10.1109/iccubea.2015.167

[58] Bini C, Giorgetti A, Giovannini E, Pelletti G, Fais P and Pelotti S, 'Human DNA Contamination of Postmortem Examination Facilities: Impact of COVID-19 Cleaning Procedure' (2022) 67(5) Journal of Forensic Sciences 1867 https://doi.org/10.1111/1556-4029.15096

[59] Rudin N, Inman K and Noureddine M, 'Letter to the Editor — Documentation, Investigation, and Disclosure of Contamination Events' (2025) 70(2) Journal of Forensic Sciences 815 https://doi.org/10.1111/1556-4029.15709

[60] Ibid

[61] Bini, supra note , 58

[62] Dammeier S, Nahnsen S, Veit J, Wehner F, Ueffing M and Kohlbacher O, 'Mass-Spectrometry-Based Proteomics Reveals Organ-Specific Expression Patterns to Be Used as Forensic Evidence' (2015) 15(1) Journal of Proteome Research 182 https://doi.org/10.1021/acs.jproteome.5b00704

[63] Oorschot R, Ballantyne K and Mitchell R, 'Forensic Trace DNA: A Review' (2010) 1(1) Investigative Genetics 14 https://doi.org/10.1186/2041-2223-1-14

[64] Smith J, Lochner H, Wet G, Singh M, Zeye M and Simon K, 'Forensic DNA Expert Evidence in the South African Context' (2025) 17(2) *African Journal of Legal Studies* 137 https://doi.org/10.1163/17087384-12340112

[65] J Romeika, 'Recent Advances in Forensic DNA Analysis' (2014) s12(01) *Journal of Forensic Research* https://doi.org/10.4172/2157-7145.s12-001

NFSU JOURNAL OF FORENSIC JUSTICE

JFJ
Volume: 4, Issue: 2
July-December 2025
E-ISSN: 2584 - 0924

of heightened visibility and expectation from the general public about the utility of forensic evidence, which is partly shaped by forensic portrayals in media and literature[66], forensic evidence can be underestimated in value or downplayed in prejudice. For example, as detailed in the work of López et al., even in the research where a microbiome can exhibit potential use in human identification, the preconceived notion about microbes and their importance or relevance to forensic science can influence their interpretation of the microbiome[67]. Bias can even influence supposedly forensic evidence analysis and opinion generation in new and innovative forensic methods.

A different type of bias, innate to forensic processes, is the technical limitations of the processes used, which can lead to possible obstacles or barriers to effective investigatory outcomes. For example, while next-generation sequencing (NGS), along with bioinformatics, is an exciting area of opportunity for forensic science, its implementation is fraught with the absence of standardised protocols, the expense of acquisition, and the difficulties related to the data analysis, interpretation and report generation[68]. New forensic technologies face similar constraints and must address these barriers to be available to forensics practitioners rather than existing as former research opportunities[69].

In addition, the increasing use of digital forensics exposes technology limitations and numerous other constraints. Digital forensic investigators are responsible for recovering and analysing electronic evidence from potentially non-compliant devices and dealing with hardware limitations and incompatibility, anti-forensics, and ever-increasing risks in cybersecurity[70]. The constantly changing technology landscape with advancing pace means that digital forensic practitioners must become adept at adapting; however, updating their toolkit is not easy, because available tools are often outdated and do not keep pace with current technology, leaving forensic investigators with tools that may not evolve with the digital landscape of evidence[71].

Adapting to changes in contamination, bias, and limitations in forensic practice will require substantial alterations and enhancements to current practice. Systematic training will promote recognition of bias to improve the training of many forensic practitioners and contribute to understanding a collective objective. Enhanced use of normalised protocols will substantially contribute to reducing and understanding contamination. Innovative technologies should bring equal involvement in research and development to improve the tools and techniques to meet forensic investigation needs.

EVOLVING FORENSIC METHODS AND THEIR IMPACT ON LEGAL STANDARDS.

Evolving forensic methods significantly impact legal standards because forensic evidence in court is more reliable, valuable, and normative. New technologies have the potential to reshape standards by creating a greater convergence between forensic practice and the law.

Modern forensic science supports law enforcement and judicial agencies and has increased the efficiency of the investigative process, using scientifically validated methodologies. Yusupov et al. stress that forensic sciences aim to provide the most support for crime investigations, leading to judicial actions based on valid and scientific techniques[72]. They are stressing that the goal is clearly to conceptualise crime investigation as an ongoing judicial action through all stages of developing scientifically validated methodology, etc. Bell et al. also articulated a clear need for forensic practices to receive scientific testing and quality assurance beyond the two levels, which some forensic practices have not chemically or empirically validated

[66] Ibid
[67] C López, A Vidaki and M Kayser, 'Integrating the Human Microbiome in the Forensic Toolkit: Current Bottlenecks and Future Solutions' (2022) 56 *Forensic Science International Genetics* 102627 https://doi.org/10.1016/j.fsigen.2021.102627
[68] Y Yang, B Xie and J Yan, 'Application of Next-Generation Sequencing Technology in Forensic Science' (2014) 12(5) Genomics Proteomics & Bioinformatics 190 https://doi.org/10.1016/j.gpb.2014.09.001
[69] R Ramadhan, P Setiawan and D Hariyadi, 'Digital Forensic Investigation for Non-Volatile Memory Architecture by Hybrid Evaluation Based on ISO/IEC 27037:2012 and NIST SP800-86 Framework' (2022) IT Journal Research and Development 162 https://doi.org/10.25299/itjrd.2022.8968
[70] Umar, R., Riadi, I., & Zamroni, G. (2018). Mobile forensic tools evaluation for digital crime investigation. International Journal on Advanced Science Engineering and Information Technology, 8(3), 949. https://doi.org/10.18517/ijaseit.8.3.3591
[71] Ibid
[72] V Yusupov, S Okhrimenko and Y Pilyukov, 'Modern Problems of Countering Certain Types of Criminal Offenses' (2021) https://doi.org/10.2991/assehr.k.211218.034

JFJ
Volume: 4, Issue: 2
July-December 2025
E-ISSN: 2584 - 0924

based on their methodology[73]. The standards of forensic practice listed earlier, including standards for DNA evidence, are coming to fruition, establishing a framework that greatly legitimises forensic evidence used before courts or judicial bodies.

The innovative technologies applied to current forensic methodologies, detailed by O'Brien et al., allow a complete re-evaluation of existing methodologies and practices in forensic sciences[74]. For instance, the advancements in DNA evidence have sparked much academic and other discussion, combining the increased public interest in forensic science to the possible shift that forensic science could represent a paradigm shift in criminal justice[75]. As time moves on, it is crucial that the legal community work to incorporate these improvements and methodologies into existing frameworks that reflect the changes to be discussed in standards of admissibility and application of context to forensic evidence.

At the same time, the education of students in law must transform to address or remember that forensic sciences are complex areas that require teaching and increasing the accuracy of developing legal order, so that lawyers do not apply forensic evidence ineffectively due to their ignorance of forensic processes. Ali highlights the need to include forensic science in legal education to develop specialised legal practitioners who are trained and will be competent to apply the value of forensic evidence[76]. It is acknowledged that a lawyer's understanding of their role in forensic science often has a significant influence on a court's decision that is made or judgment handed down because the lawyer was or was not aware of forensic science's capabilities and development of "the standard" (Romanos, 2022).

Forensic science developments have led to discussions on a global scale associated with standardising forensic practice. Research from He and Li demonstrated that the push towards developing and standardising forensic practice is occurring in different jurisdictions to ensure consistent and reliable forensic application worldwide (He & Li, 2021). It is an informative practice, and it is possible, non-standard, and inconsistent in unreliable applications. The establishment of the National Commission on Forensic Science in the United States identifies that the legal and judicial systems recognised the need for comprehensive standards and guidelines governing forensic practices[77].

Finally, emerging areas of study and effort, such as digital forensics, argue for the redefinition of law to meet the needs of the evidence and the context of accepting evidence. As Rogers articulates, it is clear that digital forensics has evolved to understand the significance of electronic evidence to disputes about relationships and context, which is the starting point of evidence based on existing legal practices.[78]

COMPARATIVE STATEMENT ON ADMISSIBILITY STANDARDS

A comparative statement on admissibility standards of evidence for India and the USA demonstrates distinct differences and some similarities. In general, this analysis examines the legal frameworks, types of evidence, judicial discretion, and norms within which admissibility occurs in each country. This model also incorporates recent studies to highlight changes and impacts within the frameworks. The main differences and similarities are also presented in a tabular form for convenience.

Differences

Legal Framework: The Federal Rules of Evidence, which outline rules that judges must follow, are the basis of admissibility standards in the USA. In the Indian legal system, the applicable statute is the Indian Evidence Act of 1872. This statute expands into numerous areas of evidence and allows expansive flexibility

[73] S Bell, S Sah, T Albright, S Gates, M Denton and A Casadevall, 'A Call for More Science in Forensic Science' (2018) 115(18) *Proceedings of the National Academy of Sciences* 4541 https://doi.org/10.1073/pnas.1712161115

[74] O'Brien C, Popovic K and Fitzgerald R, 'Science in the Court: Pitfalls, Challenges and Solutions' (2015) 370 Philosophical Transactions of the Royal Society B: Biological Sciences https://doi.org/10.1098/rstb.2015.0062

[75] R Julian, S Kelty, C Roux, P Woodman, J Robertson, A Davey and R White, 'What Is the Value of Forensic Science? An Overview of the Effectiveness of Forensic Science in the Australian Criminal Justice System Project' (2011) 43(4) Australian Journal of Forensic Sciences 217 https://doi.org/10.1080/00450618.2011.610820

[76] M Ali, 'Forensic Science Integration in Legal Education: A Paradigm Shift for Strengthening Legal Expertise in Pakistan' (2023) 32(46) Journal of Legal Studies 101 https://doi.org/10.2478/jles-2023-0014

[77] J Butler, 'Recent Activities in the United States Involving the National Commission on Forensic Science and the Organization of Scientific Area Committees for Forensic Science' (2016) 49(5) Australian Journal of Forensic Sciences 526 https://doi.org/10.1080/00450618.2016.1243153

[78] C Rogers, 'From Time Theft to Time Stamps: Mapping the Development of Digital Forensics from Law Enforcement to Archival Authority' (2019) 1(1) International Journal of Digital Humanities 13 https://doi.org/10.1007/s42803-019-00002-y

JFJ
Volume: 4, Issue: 2
July-December 2025
E-ISSN: 2584 - 0924

through provisions that afford judicial discretion in assessing evidence[79].

Hearsay Evidence: Hearsay evidence is generally not admissible in the USA unless it meets criteria that allow it to become admissible (e.g., business records; excited utterances). Generally, Indian courts are inclined to admit hearsay if the hearsay can allow the US court to accept it. This demonstrates a more lenient perspective toward the admissibility of evidence, specifically hearsay[80].

Judicial Discretion: In the USA, the judiciary often relies on case law to guide them toward admissibility decisions, limiting discretion as much as possible. Though impacted by precedent, Indian courts show more variability in evidence admissibility requirements based mainly on the judge's opinion of relevancy and necessity[81].

Expert Testimony: In the USA, the Daubert standard takes things one step further and not only requires relevancy but also that the content uses scientifically valid principles. The Indian model is somewhat laxer in providing more opportunity for the judge to assess expert testimony that implicates their discretion[82].

Key Similarities

Importance of Relevancy: Both legal systems emphasize the relevance of the evidence being presented as an important factor to be considered when collecting evidence. Both jurisdictions stipulate that evidence must relate significantly to the case before the court, although in different terminology[83].

Accused Rights: Both systems' legal frameworks acknowledge the importance of limiting the accused's rights. Jurisdictions in both systems allow a reasonable system for challenging the admissibility of evidence, which stresses the importance of the courts providing a trial relevant to the practitioner's appropriate laws[84].

Living impacts of distinct differences

Impact of COVID-19 on Hospital Admissions: Studies from both countries provide documentation of shifts in acute health admissions due to the COVID-19 pandemic. One study showed that myocardial infarction admissions decreased significantly during peak levels of COVID-19, both in India and the USA. This indicates that hospital admission had some involuntary participants in the patient's acute care and how evidence is admissible in real time by emergency health practitioners.

Prevalence of Chronic Disease: Evidence depicts the management of chronic diseases like kidney disease. Chronic patterns of illness and admissions rates differ in India and the USA, which illustrate variance in health care systems' response in the context of health evidence.

IMPACT OF LEGAL STANDARDS ON JUDICIAL OUTCOMES RELATED TO THE ACCEPTANCE OF FORENSIC SCIENCE

The interaction between legal standards and judicial outcomes, concerning the acceptance of forensic science, is a dynamic exchange representing an important driver of the reliability of evidence in courts. Legal standards like the Daubert and Frye have changed the admissibility requirements, forcing courts to examine forensic expert testimony's scientific independence and relevance more closely. The significance of Daubert v. Merrell Dow Pharmaceuticals (1993) was that expert testimony must be admissible in order for it to be used, which prompted the courts to determine, in pretrial hearings, whether or not expert testimony is reliable and relevant[85].

Legal standards in forensic science influence judicial outcomes and dictate how forensic scientists approach their work. Since lawyers

[79] R Souza, S Mhatre, B Qayyumi, G Chitkara, T Madke, M Joshi and R Badwe, 'Clinical Course and Outcome of Patients with COVID-19 in Mumbai City: An Observational Study' (2021) 11(5) BMJ Open e042943 https://doi.org/10.1136/bmjopen-2020-042943

[80] G Zachariah, S Ramakrishnan, M Das, J Abdullakutty, P Jayagopal, K Venugopal and P Mohanan, 'Changing Pattern of Admissions for Acute Myocardial Infarction in India during the COVID-19 Pandemic' (2021) 73(4) Indian Heart Journal 413 https://doi.org/10.1016/j.ihj.2021.06.003

[81] M Alam, T Aziz and V Ansari, 'The COVID-19 Pandemic and Google Search Trends' (2024) 23(1) Journal of Public Mental Health 55 https://doi.org/10.1108/jpmh-07-2023-0058

[82] J Bragg-Gresham, J Thakur, G Jeet, S Jain, A Pal, R Prasad and R Saran, 'Population-Based Comparison of Chronic Kidney Disease Prevalence and Risk Factors among Adults Living in the Punjab, Northern India and the USA (2013–2015)' (2020) 10(12) BMJ Open e040444 https://doi.org/10.1136/bmjopen-2020-040444

[83] V Mallembakam, L Yang, A Freivalds and E Kim, 'Comparison of Bus Driving Posture in USA and India' (2020) 64(1) Proceedings of the Human Factors and Ergonomics Society Annual Meeting 934 https://doi.org/10.1177/1071181320641223

[84] K Prema, A Kurien, N Gopalakrishnan, P Walker and C Larsen, 'Dense Deposit Disease: A Greatly Increased Biopsy Incidence in India versus the USA' (2019) 12(4) Clinical Kidney Journal 476 https://doi.org/10.1093/ckj/sfy125

[85] S Gatowski, S Dobbin, J Richardson, G Ginsburg, M Merlino and V Dahir, 'Asking the Gatekeepers: A National Survey of Judges on Judging Expert Evidence in a Post-Daubert World' (2001) 25(5) Law and Human Behavior 433 https://doi.org/10.1023/a:1012899030937

often lack a strong premise of research, legal professionals representing individuals accused of criminal charges are often unable or unwilling to correctly interpret or deliberately mis-conceptualise the scientific evidence[86]. This disconnect can adversely affect judicial acceptance of forensic evidence, limiting the value of the scientific analyses in criminal cases[87]. The difficulties in adherence to forensic science standards contribute to and engender discrepancies in interpretive frameworks, adding additional layers to the court process[88].

Legally, the standards governing the acceptability of forensic evidence cover both its admissibility and create the overall culture surrounding the methods used in forensic laboratories. Research indicates that standardisation in the forensic sciences can help limit errors and biases, allowing for wrongful convictions to be adequately protected against. Not following or even establishing standards will continue to expose the judicial systems to atrocities that rest on expert testimony, as juries tend not to completely grasp the complexity of the science underlying the processes of forensic science[89]. Therefore, there has been considerable discussion establishing reliance (as in standards) on the processes by which forensic conclusions were rendered, as any deviation between the processes involved creates further interrogative parsing as to those newly established processes[90].

Given the continuously evolving standards, it is growingly important for the forensic disciplines to conform to more universal scientific practices, to ensure that more recent developments, like DNA analysis, meet the greater demands of legal scrutiny and society's expectations[91]. Creating judicial faith and reliance on forensic processes is a washing process that the forensic community needs to ensure continues, as those beliefs are learned (foundational) processes that will provide the best examples of the recently evolving standards. Workshops meant to help legal professionals grasp scientific principles that underlie forensic evidence and its acceptance as provable rationale have also proven to alter perceptions of jurors and judicial outcomes[92]. The law and courts rely more on a proper exchange between allied professions, creating an urgency for a redesign of sorts in legal practitioners and forensic education that promotes relationships involving legal and forensic professionals.

It is highly detrimental that jurors do not truly understand the nature of forensic evidence submission and how reliable it can be. Further, jurors are not often equipped to reliably distinguish between reliable, scientifically sound practices and circumstances that detract from or eliminate any reliability or scientific evidence proposed ultimately to the jury for consideration. Thus, significant further clarity and education on standards of practice in forensic sciences are needed.[93]Even more unfortunate, the interest in forensic science has expanded, heavily relying on and reinforced by the media. Strange expectations of forensic sciences continue, highlighting the importance of further education and discussions with serious educational needs in the courtroom.[94]

CONTAMINATION AND BIAS ISSUES.

Contamination of forensic evidence is problematic for the integrity of criminal investigations. Evidence that has been contaminated can lead to wrongful convictions or the exclusion of forensic analysis evidence that should be a critical part of a case. As noted by Smith et al., adherence to the protocols and requirements is critical to the integrity of forensic DNA evidence; without an assertion of

[86] Ibid
[87] Saks MJ and Koehler JJ, 'The Coming Paradigm Shift in Forensic Identification Science' (2005) 309(5736) *Science* 892 https://doi.org/10.1126/science.1111565
[88] M Page, J Taylor and M Blenkin, 'Forensic Identification Science Evidence Since Daubert: Part II—Judicial Reasoning in Decisions to Exclude Forensic Identification Evidence on Grounds of Reliability' (2011) 56(4) Journal of Forensic Sciences 913 https://doi.org/10.1111/j.1556-4029.2011.01776.x
[89] Saks M and Koehler J, 'The Coming Paradigm Shift in Forensic Identification Science' (2005) 309 Science 892 https://doi.org/10.1126/science.1111565
[90] Fournier L, 'The Daubert Guidelines: Usefulness, Utilization, and Suggestions for Improving Quality Control' (2016) 5(3) Journal of Applied Research in Memory and Cognition 308 https://doi.org/10.1016/j.jarmac.2016.06.012
[91] Saks , supra note , 87
[92] McKay J, Martín M, Ascolese M and DiEmma G, 'North Carolina State University and the Forensic Technology Center of Excellence Two-Part Virtual Workshop Series: Qualifications of an Expert Witness for Legal Professionals—The Daubert and Frye Standards' (2023) https://doi.org/10.3768/rtipress.2023.cp.0017.2312
[93] Gatowski S, Dobbin S, Richardson J, Ginsburg G, Merlino M and Dahir V, 'Asking the Gatekeepers: A National Survey of Judges on Judging Expert Evidence in a Post-Daubert World' (2001) 25 Law and Human Behavior 433 https://doi.org/10.1023/a:1012899030937
[94] Grivas C and Komar D, 'Kumho, Daubert, and the Nature of Scientific Inquiry: Implications for Forensic Anthropology' (2008) 53 *Journal of Forensic Sciences* 771 https://doi.org/10.1111/j.1556-4029.2008.00771.x

those protocols prior to collection, packaging, and transporting, errors can also occur, impacting the evidentiary value of the samples[95]. Olaborede and Walt also suggest that convictions based on an isolated piece of forensic evidence are troubling because scientific validation of widely used forensic techniques, including fingerprint and bite mark evidence, leads to bias and wrongful convictions[96].

Bias is also a recurrent theme in forensic evaluations. Expectations of forensic evidence can indirectly influence how evidence is interpreted and presented. For example, forensic practitioners can consciously or subconsciously favour conclusions that support findings that fit the prosecution's story.[97]A recent research project by Grant emphasised the importance of being aware of contextual bias in analysts to control for potential effects on outcomes in the justice system. Validation studies could help foster objectivity in conclusions.[98]

Technological Constraints and Developments

The continuing advancement of forensic technologies presents both positive opportunities and challenges. Advancements in forensic science have led to significant improvements in evidence collected and its interpretation in the legal process, especially in DNA profiling methods, but require complex validation. Rakoff and Liu explain that some prosecutions have relied on DNA evidence to support their findings. However, it has also demonstrated that all wrongful convictions rely heavily on inferior forensic evidence.[99]If new forensic technologies may incriminate an individual, validation standards must be established before they are offered as evidence.

With these advancements come gaps surrounding forensic technology available to practitioners. Carr et al. suggest there is a disparity of public trust in forensic procedures due to a lack of transparency and scientific reliability. Their findings stress that heavier collaboration between forensic scientists and legal representatives may help explain the growing disconnection and understand how complex the scientific processes can be[100]. Similarly, cloud forensics is introducing new challenges surrounding standard methodology for collecting and reporting electronic evidence[101] that enable absolute forensic integrity. We must continue collaborating across our advancements' legal, scientific, and technological areas.

Providing Scientific Integrity and Acceptance in the Legal System

The challenges to ensure the scientific integrity of forensic evidence may seem insurmountable. Daubert asks for scientific evidence to be reliable and relevant. However, the interpretation of the criteria is still inconsistent[102]. Many forensic disciplines face exclusion because they cannot meet admissibility requirements that require reproducibility (i.e. to state the same or similar findings independently) and bias control (the learned skill of the analyst). If forensic evidence becomes increasingly doubtful or is excluded, it jeopardises the judicial system's acceptance of these technologies and science[103]. Even if forensic evidence is admissible, judicial understanding of scientific challenges is often limited. Judicious professionals can find it very difficult to understand and describe the implications of scientific findings or principles during trials[104].

[95] Smith J, Lochner H, Wet G, Singh M, Zeye M and Simon K, 'Forensic DNA Expert Evidence in the South African Context' (2025) 17(2) African Journal of Legal Studies 137 https://doi.org/10.1163/17087384-12340112

[96] Olaborede A and Walt L, 'The Dangers of Convictions Based on a Single Piece of Forensic Evidence' (2020) 23 Potchefstroom Electronic Law Journal/Potchefstroomse Elektroniese Regsblad 1 https://doi.org/10.17159/1727-3781/2020/v23i0a6169

[97] Edmond G, 'Forensic Science Evidence, Adversarial Criminal Proceedings, and Mainstream Scientific "Advice"' (2019) 760–785 https://doi.org/10.1093/oxfordhb/9780190659837.013.39

[98] Grant, T. (2022). The idea of progress in forensic authorship analysis.. https://doi.org/10.1017/9781108974714

[99] Rakoff J and Liu G, 'Forensic Science: A Judicial Perspective' (2023) 120 Proceedings of the National Academy of Sciences https://doi.org/10.1073/pnas.2301838120

[100] Carr S, Piasecki E and Gallop A, 'Demonstrating Reliability through Transparency: A Scientific Validity Framework to Assist Scientists and Lawyers in Criminal Proceedings' (2020) 308 Forensic Science International 110110 https://doi.org/10.1016/j.forsciint.2019.110110

[101] I Orton, A Alva and B Endicott-Popovsky, 'Legal Process and Requirements for Cloud Forensic Investigations' (2015) 332–375 https://doi.org/10.4018/978-1-4666-6539-2.ch016

[102] M Page, J Taylor and M Blenkin, 'Forensic Identification Science Evidence Since Daubert: Part II—Judicial Reasoning in Decisions to Exclude Forensic Identification Evidence on Grounds of Reliability' (2011) 56(4) Journal of Forensic Sciences 913 https://doi.org/10.1111/j.1556-4029.2011.01776.x

[103] Ibid

[104] D Magherescu, 'Achieving Judgment by Means of Forensic Science During the Criminal Proceedings in

Enhancing the interdisciplinary education of judges, lawyers, and forensic professionals is important to address barriers to public trust and legitimacy. Judges recognise that enhanced education allows more informed analysis of the scientific requirements for excellence (more legally literate) from both sides. Chin et al. propose that endorsing open forensic science encourages public transparency and increases awareness of scientific principles surrounding forensic examination[105]. Open forensic science publications may promote public trust and acceptance of forensic evidence during a criminal trial.

CONCLUSION AND SUGGESTIONS

Forensic Protocols and Standards Improvement

The reliability and credibility of forensic evidence can be improved by implementing robust protocols and standards across different forensic science fields. Evidence suggests that the strengths and weaknesses of forensic methods, such as bite mark analysis, can shape the formulation of standardised protocols to improve investigation [106]. Moreover, it is important to be aware of the inconsistencies in how forensic evidence is processed and analysed by different forensic scientists. Research has demonstrated significant inconsistencies about how forensic scientists comply with the chain of custody, underscoring the importance of protocols[107]. The groundwork for standardisation could start with capacity building and developing action plans to implement consistent best practices with ongoing, current, continuous education (and training). Thus, forensic laboratories can better align scientific principles with judicial expectations, thus improving rigour in their analysis and accepting their findings by courts[108].

Forensic Science Capacity Building in India

Capacity building in forensic science is critically important, especially in developing countries like India. There is an apparent necessity for capacity-building initiatives for training and development of forensic professionals, infrastructure improvement, and research and training for professional forensic scientists, according to international professional expectations[109]. For example, integrating next-generation sequencing technology into forensic science courses will train and develop the skills of new forensic scientists to fulfil their educational competencies in forensic DNA analysis and capitalise on existing gaps in training in forensic profiling methodologies[110]. In addition, cooperation between government agencies and the academic sector can facilitate the coordination of resources and the effectiveness of forensic education[111]. A developed forensic science framework in India will help optimise local capacity and further India's credibility and legitimacy in the international forensic science arena[112].

International Harmonisation of Best Practice

International harmonisation of best forensic science practices is essential for credible evidence within boundaries and jurisdictions. Through interdisciplinary collaboration, knowledge can spread, and methods consistent with best practice can be developed[113]. National

Romania' (2022) 8(2) Revista Brasileira De Direito Processual Penal https://doi.org/10.22197/rbdpp.v8i2.672

[105] J Chin, G Ribeiro and A Rairden, 'Open Forensic Science' (2019) 6(1) Journal of Law and the Biosciences 255 https://doi.org/10.1093/jlb/lsz009

[106] B S, BM A, N Fareed, M Babashet and S Srivathsa, 'Credibility of Bite Mark Analysis in Forensic Odontology: A Diagnostic Accuracy Trail' (2024) 6(1) International Journal of Forensic Medicine 18 https://doi.org/10.33545/27074447.2024.v6.i1a.71

[107] F Grigollo and R Fernandes, 'Study on the Adoption of Historical Record and Chain of Custody by Brazilian Judicial Experts from the Collection to the Disposal of Evidence: A Survey Questionnaire' (2024) 18(8) Revista De Gestão Social E Ambiental e08431 https://doi.org/10.24857/rgsa.v18n8-168

[108] H Almakrami and others, 'Forensic Pathology and Unnatural Death Investigations: A Systematic Review of Case Studies and Procedures' (2024) 3(7) Journal of Ecohumanism 2870 https://doi.org/10.62754/joe.v3i7.4683

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and international forensic science organisations should actively progress towards a consolidated best practice database, considering multiple legal systems, frameworks, views, institutions, organisations, and scientific practices. This cedes confidence in forensic science methods among the judiciary, and a more standardised approach to the analysis and interpretation of forensic science in courts[114]. Also, connecting with forensic professionals in different regions can provide some attention to new research opportunities, the alignment and/or standardisation of standard procedures used in forensic science, and networks for sharing resources[115].

Policy and Legal Reforms to improve reliability and acceptance

A collective movement towards policy reform is required to improve the reliability and acceptance of forensic evidence in the justice system. The development of open, clear, and structured legal frameworks outlining criteria for the admissibility of forensic evidence, and an ongoing network education-focus (for judges and related practitioners) detailing relevant science collaboration on an as-needed basis, should take top priority for forensic evidence in the justice system[116]. The actions advocated by Earwaker et al., calling for forensic science practices to shift as a culture can potentially contribute to better decision-making on projects which require forensic evidence[117]. Additionally, the development of feedback practices in forensic laboratories could be a step towards an iterative development model, accommodating procedures, practices, and products with feedback from science and/or expert opinion (2024). These measures will help develop a more worthy foundation and acceptance for forensic evidence in the justice system, whilst retaining the use of robust science within the justice context.

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