

Reasons for Potential Unreliability of DNA Evidence: A Critical Examination

Md. Imran Wahab

IPS, Inspector General of Police, West Bengal

Abstract:

DNA evidence is widely regarded as the "gold standard" in forensic science because of its capacity to accurately identify individuals and exonerate the innocent. However, several factors cast doubt on its reliability in criminal investigations. This study offers a comprehensive exploration of critical issues influencing the trustworthiness of DNA evidence, including errors in evidence collection, overlooking additional DNA samples at the crime scene, the absence of credible witnesses during searches, and the lack of video documentation throughout the processes of seizure, transportation, and lab analysis. Other concerns include human errors, inconsistent DNA analysis protocols among forensic laboratories, and potential contamination during sample collection. Furthermore, the research delves into laboratory errors, subjective interpretations, and existing biases. There is an increasing worry regarding the excessive reliance on DNA evidence without sufficient investigative corroboration, along with the potential misinterpretation of statistical probabilities by jurors. The article also examines ethical issues surrounding the expansion of DNA databases, privacy violations, and familial DNA searches. Citing pivotal academic studies and landmark legal cases like those of O.J. Simpson and Amanda Knox, this analysis highlights the pressing need for rigorous standards to govern the ethical use of DNA evidence in the criminal justice system.

Keywords: DNA Evidence, Forensic Evidence, Contamination, Degradation, Chain of Custody, DNA Transfer.

1. Introduction:

DNA evidence is only as trustworthy as other circumstantial evidence. Like fingerprints, DNA can indicate that an individual's genetic material was found at a specific location, but it doesn't fully explain how or why it was there. While DNA collected from a crime scene can serve as a significant connection to a suspect, it does not conclusively establish guilt. DNA can be transferred in various ways, such as from earlier interactions or accidental contamination. Therefore, it is crucial to examine the circumstances surrounding the collection and storage of DNA alongside other evidence to accurately assess a person's involvement in a crime. Only a comprehensive analysis can provide a clearer understanding of the situation.

The likelihood of DNA being transferred to a crime scene without direct involvement of the suspect relies on various factors, including circumstances, transfer method, and exposure duration. Secondary transmission increases contamination risk, as even brief contact can transfer small DNA amounts, complicating definitive guilt without supporting evidence despite forensic efforts. DNA sample exchange may result from contamination, mislabeling, or human error in collection, storage, or analysis, potentially

leading to wrongful convictions in forensic settings. To reduce this risk, implement strict chain of custody, verify labels, use tracking systems, conduct audits, and involve more technicians with advanced technologies.

Sample contamination during collection, transport, or analysis can lead to unreliable results, compromising DNA integrity. Human error and tampering increase the risk of inaccuracies, potentially causing significant legal consequences. To mitigate these issues, stringent quality control measures, standardized procedures, thorough training, and regular audits are essential for reliable forensic DNA analysis.



To persuade the court that the DNA sample links to the accused, the investigative agency must establish an unbroken chain of custody, documenting who handled the sample. They should provide credible scientific evidence through methods like PCR or STR profiling, highlighting the rarity of the DNA match. Anticipating defense arguments, the agency should present evidence of the accused's presence at the crime scene. Further, expert testimony can clarify the analysis process, reinforcing the sample's connection to the accused through compelling evidence and documentation.

2. Failure of DNA Evidence:

- **The Phantom of Heilbronn Case:** The Phantom of Heilbronn case in Germany highlights the risks associated with unreliable DNA evidence. Between 1993 and 2009, a woman's DNA was detected at more than 40 crime scenes, causing investigators to believe they were dealing with a serial killer. Eventually, it was revealed that contamination had taken place due to cotton swabs handled by a factory worker, underscoring the dangers of improper handling of forensic evidence.
- **The Amanda Knox Case (Italy):** Amanda Knox and her co-defendant were originally found guilty

based on DNA evidence, which was subsequently called into question due to concerns over contamination and improper handling of forensic samples. Insufficient awareness regarding the limitations of DNA analysis contributed to the initial miscarriage of justice.

- **The O.J. Simpson Trial Case (USA):** DNA evidence was pivotal in the trial; however, the jury's unfamiliarity with the nuances of forensic science, combined with apprehensions about how the police managed the evidence, fostered doubt about the credibility of the DNA findings. This scepticism significantly contributed to the jury's decision, ultimately leading to Simpson's acquittal in this high-profile case.
- **The Sally Clark Case (UK):** Sally Clark's wrongful conviction for the deaths of her children stemmed partly from significant misinterpretations surrounding DNA evidence and statistical probabilities by both the judge and the jury. This tragic case underscored the critical importance of properly understanding and interpreting forensic evidence, as well as ensuring that expert testimony is both credible and reliable in judicial proceedings.
- **The Sean Hodgson Case (UK):** In 1982, Sean Hodgson was found guilty of murder, largely due to the forensic evidence presented during his trial. However, significant advancements in DNA testing many years later resulted in his exoneration. The jury's limited understanding of DNA evidence hindered their ability to thoroughly evaluate its credibility, ultimately affecting the integrity of the verdict reached in his case.

3. Literature Review:

The application of DNA evidence in criminal investigations has elicited both commendation and caution among diverse forensic professionals, who offer distinct perspectives on its strengths and weaknesses.

Dr. John Butler regards DNA as a revolutionary asset in criminal inquiries, particularly with the widespread implementation of Short Tandem Repeat (STR) analysis, which effectively connects suspects to crime scenes. Nonetheless, he cautions against the mishandling of samples, as contamination can jeopardize the accuracy of results (Butler, 2012).

Dr. Peter Gill, a trailblazer in forensic DNA, underscores the challenges associated with interpreting mixed DNA profiles. He warns that despite the potency of DNA evidence, misinterpretations - especially with complex mixtures - could result in wrongful convictions. Gill advocates for enhanced guidelines for analysing mixed and low-copy number (LCN) DNA to reduce errors (Gill et al., 1998).

Professor William Thomson (Thomson, 2006) maintains a cautious perspective on DNA evidence, asserting it should not be viewed as infallible despite its utility in investigations. He warns of potential human errors in laboratories, such as sample contamination, mislabeling, and flawed DNA interpretations, which can compromise evidence reliability. Emphasizing the challenges of low-copy number (LCN) DNA and mixed samples, he insists that DNA findings should be supported by additional evidence, like witness accounts or physical proof, to prevent wrongful convictions.

Dr. Sheila Jasanoff, a legal scholar, expresses concerns about the "black-box" nature of forensic labs, advocating for greater transparency and scrutiny of laboratory processes to guarantee the reliability of DNA findings. She contends that blind trust in science, without recognition of its limitations, can lead to unjust outcomes (Jasanoff, 2004).

Dr. Frederick Bieber supports the implementation of familial DNA searches in criminal investigations, pointing out their success in resolving previously unsolved cases. However, he warns that these methods raise privacy issues, as innocent relatives may become suspects (Bieber et al., 2006).

Dr. Simon Ford critiques the potential for "contextual bias" in DNA interpretation, suggesting that forensic professionals might interpret results to align with the objectives of the prosecution. He argues that this bias highlights the necessity for independent validation of DNA evidence (Ford, 2010).

Dr. Michael Saks contends that DNA is frequently overemphasized in legal settings, as jurors may perceive it as unequivocal evidence of guilt. He stresses the importance of educating legal practitioners about the complexities of DNA analysis to avoid excessive dependence on flawed evidence (Saks & Koehler, 2005).

Dr. Robin Williams raises ethical concerns regarding the expansion of DNA databases. He argues that, although beneficial in solving crimes, these databases also pose civil liberty risks, especially when people are unjustly included in DNA profiles (Williams & Johnson, 2005).

Dr. Mark Jobling addresses the constraints of Y-STR analysis, utilized for tracing male lineage, stating that it does not possess the same discriminatory power as autosomal STR. He acknowledges that this technique can be advantageous in specific situations, but reliance on it could lead to inaccurate conclusions (Jobling & Gill, 2004).

Professor David Lazer calls for careful oversight of DNA databasing practices, warning against potential governmental misuse. He suggests that while DNA databases can enhance investigative capabilities, their growth should be paired with stringent legal protections to safeguard individual privacy (Lazer, 2004).

These expert viewpoints illustrate a shared understanding that while DNA serves as an essential instrument in resolving crimes, it necessitates meticulous interpretation, ethical considerations, and corroboration with other forms of evidence to ensure justice is upheld.

4. Causes for Unreliability of DNA Evidence:

This section examines elements that could compromise the reliability of DNA evidence. Each aspect is supported by references to scientific research and legal cases that demonstrate the limitations and difficulties associated with its application in forensic science. Covering topics such as contamination, degraded samples, low-template DNA, chain-of-custody issues, and over-reliance on DNA within the justice system, it offers a detailed look at its potential shortcomings.

- **Contamination:** DNA samples can become contaminated during the collection, storage or analysis process. This contamination can introduce DNA from unintended sources, leading to erroneous conclusions. Research has shown that even minimal contamination can significantly alter outcomes, as highlighted in the Amanda Knox case.
- **Degraded DNA:** In cases involving older or poorly preserved samples, DNA can degrade over time. Degraded DNA can produce incomplete profiles, resulting in false exclusions or inclusions. Forensic experts have recognized the difficulty in obtaining credible profiles from these compromised samples.
- **Low template DNA:** Low template or touch DNA involves the analysis of very small amounts of genetic material. Although modern technologies have made this analysis possible, studies suggest that such small amounts are highly susceptible to amplification errors and stochastic effects, making the results unreliable.
- **Custody Chain Issues:** Maintaining a proper chain of custody is critical to ensuring the reliability of DNA evidence. Any deficiencies in documentation or tampering may call into question the authenticity of the evidence, as stated in O.J. Simpson trial.
- **Risk of False Positives and Complex Mixtures:** Many DNA samples contain a mixture from multiple contributors. Isolating these profiles is complex and can lead to misidentification, especially if statistical methods or algorithms are used incorrectly. The occurrence of false positives, along with the

difficulties in interpreting mixed DNA profiles, can result in mistakes or complications when trying to draw accurate inferences.

- **Incidental Transfer Issues:** DNA can be transferred from one surface to another or from one person to another by secondary or tertiary means. Research has shown that this can lead to the discovery of DNA at a crime scene, even if the individual did not come into direct contact with it.
- **Partial DNA Profiles:** Degraded or low-template samples may produce partial DNA profiles. These incomplete profiles increase the risk of false matches, which can lead to the wrongful conviction of innocent people.
- **Laboratory Errors:** Human errors in laboratories - such as mislabeling samples, cross-contamination, or inaccurate data interpretation - can lead to unreliable results. Such errors have been identified as significant factors in many wrongful convictions.
- **Subjectivity in Interpretation:** Interpretation of DNA evidence, especially in cases involving mixed or degraded samples, often requires subjective judgment. Studies have revealed that two analysts can arrive at different interpretations of the same data, raising concerns about consistency and reliability.
- **Statistical Misinterpretation:** Jurors and lawyers can misinterpret the statistical probabilities associated with DNA evidence. A misunderstanding of probabilities can lead to DNA evidence being given a more definite meaning than it actually has.
- **Overreliance on DNA:** While DNA is a powerful investigative tool, overemphasizing it in an investigation can lead to the neglect of other crucial evidence. Investigators focusing only on DNA may overlook alternative explanations or evidence that could exonerate a suspect.
- **Overvaluation of Probative Worth:** DNA evidence is frequently regarded as completely reliable, yet its probative worth can often be inflated. A high probability of a match does not establish a definitive connection to the crime when other contextual elements are not taken into account.
- **Lack of Uniformity in Laboratory Standards:** Not all forensic laboratories adhere to recognized accreditation standards or undergo regular audits. DNA evidence produced by laboratories that do not maintain high quality procedures can be unreliable. Discrepancies in laboratory practices and interpretive standards may result in inconsistencies in DNA analysis and reporting across various cases and jurisdictions.
- **The Complexity of Family DNA:** Searching for familial DNA can lead to false positives due to genetic similarities between relatives. Such evidence can lead to wrongful convictions if not carefully analysed in conjunction with other evidence.
- **Database Limitations:** Although DNA databases are powerful tools, they can generate false matches due to the sheer number of profiles they contain. Statistical anomalies can arise in large databases where random matches can happen by chance, as shown in some cases in the UK.
- **Limited Discernment:** In populations with low genetic diversity, DNA profiles may lack sufficient discriminatory power. This increases the chances of random matches, especially in small or tight-knit communities.
- **Neglect of Contextual Factors:** DNA analysis fails to provide insights into the context or conditions surrounding the transfer of DNA, such as the timing or nature of the activities involved, potentially resulting in incomplete or misleading conclusions. DNA evidence presented without proper contextualization can be misleading. For example, the mere presence of DNA at a crime scene does not necessarily indicate participation in a crime, as the DNA may have been deposited innocently.

- **Technological Limitations:** Although DNA technology has progressed significantly, it remains imperfect. Rapid DNA testing offers swift results; however, this speed might compromise accuracy, particularly when conducted in non-accredited labs. Balancing efficiency with reliability is crucial to ensure that these advancements genuinely enhance forensic and diagnostic applications without jeopardizing their precision.
- **Bias in Interpretation:** Analysts may be affected by cognitive biases, especially if they know case details or suspect profiles. There have been documented cases where analysts' conclusions were influenced by extraneous information, compromising the objectivity of DNA evidence.
- **Evolving Legal Standards:** As DNA technology advances, legal standards governing its admissibility have not evolved uniformly. In some jurisdictions, laws allowing unreliable DNA evidence in court can lead to wrongful convictions.
- **Reassessing the Evidentiary Weight of DNA:** DNA evidence frequently receives excessive emphasis in court proceedings, leading jurors to perceive it as irrefutable confirmation of a defendant's guilt. Legal experts have identified this phenomenon as a significant contributor to cases of wrongful convictions. The reliance on seemingly infallible DNA results can overshadow other critical evidence, resulting in severe consequences for justice and the accused.
- **Absence of Independent Witness:** The lack of independent witnesses during a search and seizure operation can raise doubts about the integrity of the process. This absence may lead to perceptions of misconduct or bias within the investigating agency, undermining the credibility of the operation. Such assumptions can call into question the legitimacy of the evidence collected and the motivations behind the agency's actions.
- **No Videography:** The absence of videography documenting the search, seizure operation, transportation of DNA evidence, and laboratory analysis undermines the confidence in the entire procedure. This lack of recorded evidence allows the defense to challenge the reliability and integrity of the entire process, raising doubts about the validity of the evidence and the subsequent conclusions drawn from it.

The need for careful handling of DNA evidence is highlighted by various concerns, reinforcing the necessity of combining it with other evidence and contextual details to achieve just and accurate results in legal matters. Neglecting to adhere to strict procedures can lead to significant legal consequences and erode public trust in the justice system.

Law enforcement and legal professionals must prioritize strict protocols when handling DNA evidence. This ensures the protection of individuals' rights while aiding in the pursuit of truth in criminal investigations, ultimately contributing to a fair and just legal process. Consequently, it is essential to pay close attention to every detail during the evidence handling process. This diligence is vital for delivering justice and upholding the integrity of the legal system, ensuring that everything is conducted accurately and fairly.

5. How an Innocent Person Can Defend Themselves When DNA is Found at a Crime Scene:

An innocent individual may contest the presence of their DNA by questioning the likelihood of contamination, transfer, or errors in interpretation that could occur during forensic analysis. This raises valid concerns about the integrity of the evidence and highlights potential flaws in the procedures used to obtain and analyse DNA samples.

- **Establish an Alibi:** Provide solid proof of whereabouts during the crime, like witness testimonies or CCTV footage.
- **Challenge Chain of Custody:** Question the handling and storage of DNA evidence, looking for contamination signs.
- **Mixed DNA Samples:** Argue the presence of multiple DNA sources complicates guilt.
- **Sample Degradation:** Assert that damage to DNA samples affects the accuracy of results.
- **Character Witnesses:** Gather endorsements from family and friends to support claims of innocence.
- **Question the Collection Process:** Challenge the reliability of the DNA evidence by suggesting it may have been mishandled or improperly stored, indicating possible contamination.
- **Explain Innocent Connections:** Clarify how their DNA might have ended up at the crime scene due to legitimate encounters, such as prior visits. Propose that the DNA could have been accidentally transferred during evidence collection or introduced through external environmental factors. Argue that innocent interactions like handshakes, hugs, or sharing personal items might have inadvertently left DNA at the scene.
- **Highlight Secondary Transfer:** Stress the potential for DNA transmission through indirect contact, possibly through items or individuals that connected both the crime scene and the accused.
- **Cite Shared Space Transfer:** Argue that their DNA could have been deposited on communal surfaces - like public areas - before being later carried to the crime scene.
- **Introduce Professional Contamination:** Suggest that contamination might have occurred due to police officers, crime scene investigators, or lab technicians handling the evidence.
- **Clarify Prior Presence:** Assert that the individual had justifiable reasons for being at the location before the crime occurred, which would account for their DNA being found there.
- **Ponder Evidence Fabrication:** Present the theory that DNA could have been intentionally planted to falsely implicate them.
- **Challenge DNA Testing Techniques:** Question the credibility of the specific DNA testing methods utilized, particularly if they have a history of inaccuracies.
- **Address Sample Integrity:** Confirm that the DNA sample's integrity may have been compromised over time or by environmental factors, impacting the reliability of the findings.
- **Note Possible Lab Errors:** Emphasize the potential for human errors in DNA analysis that could lead to incorrect conclusions.
- **Point to Sample Size Issues:** Argue that the DNA sample may be too small to make definitive conclusions, risking false positives.
- **Question Sample Quality:** Challenge the integrity of the DNA sample, as low-quality samples can yield misleading results.
- **Highlight Lab Cross-Contamination:** Suggest that DNA from unrelated cases might have inadvertently contaminated the sample during lab analysis.
- **Identify Database Errors:** Argue that inaccuracies in the DNA database or identification mistakes might have incorrectly linked the DNA to the accused.
- **Engage Forensic Experts:** Collaborate with forensic specialists to scrutinize DNA evidence, potentially revealing errors in its collection or interpretation. Introduce expert testimony that questions the validity or reliability of the DNA findings.

- **Emphasize Absence of Motive:** Present evidence demonstrating a lack of motive to commit the crime, further bolstering their claim of innocence.
- **Gather Character Witnesses:** Compile statements from family, friends, or colleagues who can vouch for the individual's character and support their assertion of innocence.
- **Advocate for Further DNA Testing:** Request additional DNA analyses that may help identify other potential suspects, thereby distancing suspicion from themselves.
- **Assess Eyewitness Reliability:** Investigate the dependability of eyewitness identifications, considering factors like stress or poor visibility that could distort memory.
- **Secure Legal Representation:** Engage a lawyer with expertise in DNA-related cases who can competently dispute the evidence presented by the prosecution and formulate a robust defense strategy tailored to your situation. Their experience is crucial for navigating the complexities of such cases effectively.
- **Raise Public Awareness:** If warranted, utilize media or social platforms to bring attention to the case, potentially garnering public support and encouraging law enforcement to carry out a thorough investigation.
- **Underscore Lack of Supporting Evidence:** Highlight that solely relying on DNA evidence is inadequate for securing a conviction, as it must be supported by additional evidence, including motives, eyewitness testimonies, or fingerprints, to establish a comprehensive and convincing case in a court of law.

6. Foreign Court Judgments on DNA Evidence:

The admissibility, reliability, and implications of DNA evidence have been the subject of a number of landmark decisions in international courts. Some examples follow:

- In the case of *S. and Marper v. United Kingdom* (2008), the European Court of Human Rights determined that the permanent storage of DNA profiles belonging to individuals who had been acquitted breached Article 8 of the European Convention on Human Rights, which safeguards the right to privacy. This ruling led to reforms in DNA retention policies throughout Europe, aimed at reconciling privacy concerns with the requirements of law enforcement.
- In the case of *Prosecutor v. Krstić* (2001), the International Criminal Tribunal for the Former Yugoslavia (ICTY) employed DNA evidence to recognize victims from mass graves in Bosnia and Herzegovina. This case underscored the significance of DNA profiling within international criminal law, especially for identifying victims of genocide and mass atrocities.
- In the case of *R v. Wallace* (2004), the Court of Appeal of New Zealand highlighted the necessity of clearly conveying likelihood ratios in DNA profiling, especially in instances involving partial matches. The court warned against the dangers of over-interpreting DNA evidence to prevent juries from being misled by incomplete or unclear results.
- In the case of *R. v. Stillman* (1997), the Supreme Court of Canada determined that acquiring DNA samples from a suspect without their consent breached the Canadian Charter of Rights and Freedoms, unless specific protocols were adhered to. This ruling emphasized that even though DNA evidence is crucial, its collection must uphold constitutional rights.
- In the case of *S v. Maqhina* (2001), the Supreme Court of Appeal of South Africa declared that although DNA evidence can be compelling in a murder case, it should be approached with caution. The court

underscored the necessity of thorough collection, analysis, and preservation of the chain of custody to guarantee its dependability.

- In the case of *R v. Karger* (2001), the Supreme Court of South Australia addressed the interpretation of mixed DNA samples that involve several individuals. The court highlighted the importance of expert testimony to elucidate intricate DNA evidence, particularly in instances where the sample may be partial, degraded, or ambiguous.
- In the *R v. Dohoney & Adams* case, the UK Court of Appeal established guidelines for presenting DNA evidence in trials: scientists must present DNA comparisons and random occurrence ratios, the prosecution must provide sufficient calculation details to the defence, and databases used for calculations must be accessible to defence experts upon request.
- In the case of *Daubert v. Merrell Dow Pharmaceuticals, Inc.* (1993), the U.S. Supreme Court set forth the "Daubert Standard" regarding scientific evidence, which encompasses DNA. This decision mandated that judges evaluate the validity and reliability of scientific evidence, thereby establishing the criteria for the acceptance of DNA evidence in U.S. courts based on scientific rigor.

7. Indian Court Judgments on DNA Evidence:

The Supreme Court of India has examined the relevance and admissibility of DNA evidence through several landmark decisions. Here are some key rulings that have influenced the interpretation and application of DNA evidence in Indian jurisprudence:

- In the landmark case of *State of Uttar Pradesh v. Rajesh Gautam* (2003), the Supreme Court underscored the importance of DNA evidence in criminal investigations and its scientific reliability. The Court noted that while DNA findings are compelling, they should be supported by additional evidence to prove guilt beyond a reasonable doubt.
- The decision in the matter of *Selvi v. State of Karnataka* (2010) was crucial in discussing the constitutionality of using methods like narco-analysis, polygraph testing, and brain mapping, alongside DNA profiling as admissible evidence. The Court ruled that DNA profiling is scientifically sound but must be applied cautiously, ensuring that the fundamental rights of the accused are not compromised. It also stressed that evidence must be collected and submitted while adhering to legal protections.
- The Supreme Court ruling in the matter of *State of Maharashtra v. Suresh* (2008) affirmed the acceptance of DNA evidence, emphasizing its critical role in establishing identity and linking perpetrators to offenses. The judgment reinforced the notion that DNA evidence, although essential, should be considered alongside other types of evidence to uphold the fairness of a trial.
- The significant case of *Gian Kaur v. State of Punjab* (1996) addressed the admissibility of DNA evidence concerning parentage and inheritance issues. The Supreme Court recognized the scientific credibility of DNA testing in establishing biological connections and reaffirmed its importance in settling familial disputes.
- The decision in the case of *Krishna v. State of Karnataka* (2018) focused on the procedural requirements for the acquisition and presentation of DNA evidence. The Court highlighted the necessity for adherence to established protocols to maintain the integrity and reliability of DNA samples, pointing out that failures in following procedures can affect the admissibility and credibility of such evidence.
- In *Rahul v. State of Haryana*, the Supreme Court of India addressed the admissibility of DNA evidence in criminal trials, stressing the importance of stringent scientific standards and procedural safeguards.

The ruling highlights the court's commitment to integrating advancements in DNA technology with legal principles for reliable evidence in court.

- In the case of *Ramchandra v. State of Maharashtra* (2009), the Supreme Court of India upheld the acceptability of DNA evidence for proving identity and supporting criminal evidence. The court highlighted the importance of properly managing DNA samples to preserve their integrity and reliability in judicial processes.

8. Conclusion:

This situation underscores significant issues tied to an over-reliance on DNA as an infallible form of evidence, which can overshadow other crucial information. Courts sometimes fail to consider factors such as errors in evidence collection, neglecting other DNA evidence found at the crime scene or on the weapon, as seen in the Reed case, lack of credible witnesses during seizure, absence of video documentation of the seizure, transportation, and lab analysis, the reliability of laboratory experts, contamination, laboratory errors, and the integrity of the chain of custody. Failing to thoroughly evaluate DNA evidence can undermine the justice system by allowing unreliable evidence to go unchallenged. A more critical approach is necessary, where DNA is examined alongside other evidence to ensure fairness and accuracy in the legal process.

Witnesses play a crucial role in preserving the integrity of DNA evidence at crime scenes by verifying proper collection protocols. Their presence enhances the credibility of the evidence, addressing defense challenges regarding collection methods and ensuring impartiality, which bolsters the admissibility and scientific reliability of the evidence in legal proceedings.

References:

1. Butler, J. M. (2012). *Advanced Topics in Forensic DNA Typing: Methodology*. Elsevier.
2. Gill, P., et al. (1998). The interpretation of DNA evidence: A survey analysing the prevalence of mixed DNA profiles. *Forensic Science International*, 91(1), 41-51.
3. Thompson, W. C. (2006). Issues with the 'gold standard': Analysing the concerns surrounding forensic DNA evidence. *The Champion*, 30(1), 10-16.
4. Jasanoff, S. (2004). *States of Knowledge: The Co-production of Science and the Social Order*. Routledge.
5. Bieber, F. R., Brenner, C. H., & Lazer, D. (2006). Identifying criminals through their relatives' DNA. *Science*, 312(5778), 1315-1316.
6. Ford, S. (2010). Contextual bias and its influence on forensic DNA evidence. *Journal of Forensic Science*, 55(4), 1000-1005.
7. Saks, M. J., & Koehler, J. J. (2005). The impending paradigm shift in forensic identification science. *Science*, 309(5736), 892-895.
8. Williams, R., & Johnson, P. (2005). The challenges of inclusiveness, effectiveness, and intrusiveness in the evolving applications of DNA profiling for criminal investigations. *The Journal of Law, Medicine & Ethics*, 33(3), 545-558.
9. Jobling, M. A., & Gill, P. (2004). Encoded evidence: The role of DNA in forensic analysis. *Nature Reviews Genetics*, 5(10), 739-751.
10. Innocence Project. (2020). *Wrongful Convictions and DNA Evidence*.

11. Gill, P., et al. (2000). The impact of degradation on DNA: Consequences for DNA typing. *Forensic Science International*.
12. Simpson, O.J. (1995). *Trial Documentation and Analysis*.
13. Perlin, M. W. (2001). Interpreting complex forensic evidence: Challenges posed by DNA mixtures. *Legal Medicine*.
14. Van Oorschot, R. A. H., & Jones, M. K. (1997). Extracting DNA fingerprints from fingerprints. *Nature*.
15. Sjerps, M., et al. (2014). Assessing Partial DNA Profiles in Forensic Contexts. *Forensic Science International*.
16. Garrett, B. L. (2011). *The Conviction of the Innocent: Examining Failures in Criminal Prosecutions*.
17. Dror, I. E., & Hampikian, G. (2011). The role of subjectivity and bias in interpreting forensic DNA mixtures. *Science & Justice*.
18. Thompson, W. C., & Schumann, E. L. (1987). *Analysing Statistical Evidence in Criminal Trials. Law and Human Behaviour*.
19. Cole, S. A. (2005). *The Myth of Infallibility: An Analysis of Forensic Evidence in Wrongful Convictions. Legal Studies Forum*.
20. Kaye, D. H. (2001). *Analysing DNA Evidence: The Interplay of Probability, Population Genetics, and Legal Systems*.
21. Hill, C. R., et al. (2014). Familial DNA Searching: A Review of Its Benefits and Risks. *Forensic Science International: Genetics*.
22. Sutherland, R. (2016). *Analysing the UK DNA Database: Statistical Errors and False Positives*.
23. Weir, B. S., et al. (1997). *The Role of Population Genetics in Legal Proceedings and DNA Evidence*.
24. Krane, D. E., et al. (2009). Contextual effects and cognitive bias in the interpretation of forensic DNA evidence. *Forensic Science International*.
25. Houck, M. M., & Siegel, J. A. (2010). *Foundations of Forensic Science*.
26. Dror, I. E. (2015). *Addressing Cognitive Bias in Forensic Science: Progress Towards a Research-Centric Culture. British Journal of Psychology*.
27. Goodman-Delahunty, J., & Groscup, J. (2005). Jurors' Perceptions of DNA Evidence: Insights from a Public Opinion Survey. *Psychology, Public Policy, and Law*.