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REVOLUTIONIZING COLD CASE INVESTIGATIONS: THE ROLE OF DNA EVIDENCE IN UNCOVERING CRIMINAL JUSTICE

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Abstract: *Often leaving unsolved crimes that last for years or even decades, cold case investigations constitute one of the most difficult facets of the criminal justice system. DNA evidence has shown to be a game-changing weapon in resolving such cases in recent years. The passage of time often compromised traditional techniques like eyewitness testimony or physical evidence, but DNA has become a strong, unquestionable connection between offenders and crime scenes. Emphasising developments in forensic technology, including mitochondrial DNA, touch DNA and forensic genealogy, this article investigates the revolutionary influence of DNA analysis in cold case investigations. These developments have enabled the extraction of viable DNA from degraded materials, therefore resolving formerly believed unsolvable cases. The article shows how DNA evidence has given victims' families closure and rebuilt public confidence in the justice system by means of case studies including the Golden State Killer and the Cleveland Strangler. Although the use of DNA evidence has greatly improved, problems still exist including contamination, deterioration, and the possibility of false convictions. This paper also looks at the legal, ethical, and technological issues surrounding DNA use in criminal investigations. In the end, the research shows how important DNA is for contemporary forensic science and how it can provide justice even after many years.*

Keywords: *Cold Case, Forensic Evidence, DNA Analysis, Criminal Justice, Case Study*

INTRODUCTION

Cold Case investigations represent one of the most challenging and heart wrenching aspects of the justice system, as they often involve unresolved crimes that have lingered for years or even decades without resolution. These unsolved cases, filled with unanswered questions and unresolved pain, demand innovative approaches to bring justice to victims and their families. One of the most significant advancements in modern forensic science and one that has revolutionized cold case investigations, is the application of DNA evidence.[1] DNA evidence has proven to be a game changer in the criminal justice system, particularly in its application to solving cold cases. In the past, conviction often relied on eyewitness testimony, physical evidence or confession. However, these traditional methods could easily be clouded by time, memory distortions or changes in the crime scene over the years.[2] DNA analysis on the other hand serves as an incontrovertible link between the perpetrator and the crime scene. Its discovery, has led to exoneration of wrongfully convicted and conviction to those who have evaded justice for years.[3]

Advancements in forensic technology have expanded the scope of DNA evidence, enabling law enforcement to extract and analyze DNA samples from even the most deteriorated or degraded materials. The development of more sensitive DNA testing methods, such as mitochondrial DNA and touch DNA analysis, allow for the identification of perpetrators even when the evidence is scarce or compromised.[4] Thus providing a new opportunity to solving crimes that would otherwise remained unsolved

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[1] Kanchan Dogra, 'Technological Advancements in Cold Case Investigations' (*Hawk Eye Forensic*, 4 March 2024) <https://hawkeyeforensic.com/2024/01/04/technological-advancements-revolutionizing-cold-case-investigations> accessed 10 May 2025

[2] Sreejayaa Rajguru, 'Impact of DNA Evidence in Criminal Investigations and Courtroom Proceedings' [2024] SSRN Electronic Journal 1 <https://www.ssrn.com/abstract=4753118> accessed 10 May 2025

[3] Greg Hampikian, Emily West and Olga Akselrod, 'The Genetics of Innocence: Analysis of 194 U.S. DNA Exonerations' (2011) 12 Annual Review of Genomics and Human Genetics 97

[4] Salem Khalif Alketbi, 'Emerging Technologies in Forensic DNA Analysis' (2024) 1 Perspectives in Legal and Forensic Sciences 10007

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and reopening investigations that were previously deemed hopeless. Moreover, the use of DNA evidence in cold cases has had profound societal impacts. It not only brings closure to families and communities but also strengthens public trust in justice delivery system. The increasing reliance on DNA evidence as the cornerstone of modern forensic investigations ensures that individuals are held accountable for their actions, no matter how much time has lapsed. It also enhances the integrity of the judicial process by ensuring that verdicts are based on scientific evidence rather than unreliable or outdated information.[5]

In this study, the author explores the transformative power of DNA evidence in cold case investigations, detailing how its integration has reshaped forensic practices, solved longstanding mysteries and helped uncover justice in cases once thought to be lost to time. Through case studies, this article aims to highlight the undeniable role of DNA evidence in bridging the gap between past crimes and modern day justice, offering a beacon of hope in the pursuit of truth.

LITERATURE REVIEW

The application of DNA evidence in cold case investigations has revolutionized forensic science, providing unprecedented opportunities for solving long, unsolved crimes. The use of DNA profiling has been pivotal in the re-examination of evidence, leading to both the identification of perpetrators and the exoneration of the innocent. DNA evidence has emerged as one of the most powerful tools in forensic investigations, particularly in cold cases where conventional investigative methods have failed. *Matt DeLisi*[6], outlines the significance of DNA evidence in resolving cases that remain open for years. His work discusses over 100 cold cases solved using DNA, highlighting the technological advancements in forensic sciences that have enabled such breakthroughs. DNA's uniqueness to each individual (except for identical twins) makes it essential tool for linking suspects to crimes and victims, as emphasized by *Richard Saferstein*[7]. The author details the technical processes involved in DNA analysis, such as extraction, amplification through *Polymerase Chain Reaction* (PCR) and its comparison against known profiles, foundational in solving cold cases. He further restores that, DNA profiling has not facilitated the identification of criminals but also helped in securing the release of wrongfully convicted innocents.

Another notable development in solving cold cases has been the application of forensic genealogy. *Edward Humes*[8], explores how forensic genealogy has played a crucial role in solving complex cold cases. His case study on a double murder solved through DNA analysis and genealogical research is a testament to the power of integrating DNA with genealogical databases. This interdisciplinary approach has provided new avenues for investigators, especially when DNA samples from crime scenes are limited or degraded. *Colleen M. Fitzpatrick*[9], a leading figure in forensic genealogy, has contributed significantly to the integration of genealogy with DNA evidence, solving numerous cold cases through this method. Her research highlights the importance of databases like 'GEDmatch', which enables investigators to compare genetic data against a broad pool of genealogical information, opening doors to resolving cases that were previously deemed unsolvable.

While DNA evidence has proven invaluable in solving cold cases, its application is not without challenges. *James, Nordby and Bell*[10], emphasize the complexities of handling DNA evidence, especially in cold cases where samples may be degraded, contaminated or mixed. The accuracy of DNA results depends heavily on the integrity of the samples collected, a point discussed by *R.J. Parker and Peter Vronsky*[11], who caution against the potential for contamination during the collection and processing phases. Similarly, the interpretation of partial or mixed DNA profiles can be problematic, requiring careful analysis to ensure that results are not misleading. As highlighted by *Saferstein,* the advancements in DNA technology have

[5] Ankit Srivastava and others, 'Impact of DNA Evidence in Criminal Justice System: Indian Legislative Perspectives' (2022) 12 Egyptian Journal of Forensic Sciences 51

[6] Matt DeLisi, *What DNA Evidence Reveals About Criminals: Cold Case Criminology* (Kendal Hunt Publishing, 2023).

[7] Richard Saferstein and Tiffany Roy, *Criminalistics: An Introduction to Forensic Science* (Pearson Education, 2025)

[8] Edward Humes, *The Forever Witness: How DNA and Genealogy Solved a Cold Case Double Murder* (Dutton, 2022)

[9] Colleen M. Fitzpatrick and Andrew Yelser, *Forensic Genealogy* (Identifinders Intl, 2013)

[10] Stuart M. James, Jon J. Nordby and Suzanna Bell, *Forensic Science: An Introduction to Scientific and Investigative Techniques* (CRC Press, 2015)

[11] R.J. Parker and Peter Vronsky, *Forensic Analysis and DNA in Criminal Investigations: Including Cold Cases Solved* (Parker Publication, 2015)

significantly reduced those issues, but the handling of DNA remains a critical factor in ensuring the reliability of the evidence.[12]

The establishment of forensic DNA databases, such as *Combineed DNA Index System* (CODIS), has also been instrumental in advancing cold case investigations. The integration of these databases allows for the comparison of DNA profiles across jurisdictions, increasing the chances of matching evidence with suspects or linking different crimes. According to the *National Institute of Justice*,[13] the use of CODIS and similar databases has become an essential tool in the resolution of cold cases, enabling law enforcement agencies to track DNA evidence over time and across geographic boundaries. This capability has been particularly beneficial in linking serial crimes and identifying long unrecognized patterns in criminal behaviours.

EVOLUTION AND FUTURE OF DNA ANALYSIS

Since its inception in 1980s, techniques of forensic DNA analysis have changed drastically. From the time *Restriction Fragment Length Polymorphism* (RFLP) first emerged to the present use of *Forensic Genetic Genealogy* (FGG), every improvement has improved law enforcement's capacity to identify offenders, clear the innocent, and close cold cases. The most important discovery came from STR analysis's introduction in the 1990s, which allowed smaller DNA samples to be used and databases like CODIS to enable cross-jurisdictional cooperation created. Innovations like NGS and FGG keep forensic DNA analysis stretching the envelope of what is feasible. More thorough and effective research made possible by these developments, especially in cases involving degraded or mixed DNA samples, enables Forensic DNA analysis will remain a vital instrument as technology develops.[14]

Forensic DNA analysis keeps pushing the envelope of what is feasible with advancements like NGS and FGG. These developments make it possible to conduct more thorough and effective investigations, especially when dealing with damaged or contaminated DNA samples. It will continue to be an essential tool in the fight for justice as technology advances, helping to solve both past and present crimes. [15]The fact that these methods are still being developed shows how important forensic science is to the criminal justice system. DNA analysis appears to have a bright future thanks to ongoing technological and methodological developments, which will guarantee that justice is served even after decades have passed since the crime was committed.

A. Restriction Fragment Length Polymorphism Analysis (RFLP)

Developed by *Sir Alec Jeffreys* in 1984 at the University of Leicester, RFLP Analysis was the first DNA profiling technique used in forensic science. It detects variations in DNA fragment lengths resulting from restriction enzyme digestion. These fragments vary in length due to polymorphisms in the DNA sequence, which creates a unique pattern or DNA fingerprint. In this analyses, the DNA is extracted from a biological sample, then treated with restriction enzymes that cut the DNA at specific sequences. The resulting fragments are separated by *gel electrophoresis*, creating a pattern of bonds that are unique to each individual.[16] RFLP was used in one of the first high profile criminal cases in 1986 to solve the double murder of *Lynda Mann* and *Dawn Ashworth* in *Leicestershire, United Kingdom* (UK). The technique helped convict *Colin Pitchfork*, marking the first conviction based on DNA evidence. Though revolutionary, RFLP analysis was challenging to apply to limited or deteriorated samples because it required a lot of high-quality DNA. More effective and sensitive methods, like STR analysis, gradually took its place.[17]

B. Short Tandem Repeat Analysis (STR)

The gold standard for forensic DNA profiling is currently STR analysis which was developed in 1990's. STRs are short, repetitive DNA sequences that differ in length from person to person. STRs are perfect for identification because of these variations. *Polymerase Chain*

[12] Richard Saferstein, *Criminalistics: An Introduction to Forensic Science* (Pearson Education Ltd., 2014)

[13] Office of the Attorney General, 'Advancing Justice Through DNA Technology: Using DNA To Solve Crimes' (US Department of Justice, 9 September 2014) <https://www.justice.gov/archives/ag/advancing-justice-through-dna-technology-using-dna-solve-crimes> accessed 11 May 2025

[14] Deirda Jordan and DeEtta Mills, 'Past, Present, and Future of DNA Typing for Analyzing Human and Non-Human Forensic Samples' (2021) 9 Frontiers in Ecology and Evolution 646130

[15] Penelope R Haddrill, 'Developments in Forensic DNA Analysis' (2021) 5 Emerging Topics in Life Sciences 381

[16] Jane Gitschier, 'The Eureka Moment: An Interview with Sir Alec Jeffreys' (2009) 5 PLoS Genetics e1000765

[17] Ian Cobain, 'Killer Breakthrough – the Day DNA Evidence First Nailed a Murderer' *The Guardian* (7 June 2016) <https://www.theguardian.com/uk-news/2016/jun/07/killer-dna-evidence-genetic-profiling-criminal-investigation> accessed 11 May 2025

Reaction (PCR) is used to ramp up specific regions of the STR sequences, increasing the amount of DNA that can be analysed. After measuring the length of the repeats at each STR locus, the number of repeats is used to create a person's DNA profile.[18] Even though there were disagreements over evidence handling, STR analysis has been crucial in resolving high-profile cases like the *O.J. Simpson trial* in 1995, where DNA evidence was essential in proving that Simpson's blood was present at the crime scene.[19] By enabling the examination of smaller DNA samples, such as those that are deteriorated or combined with DNA from various sources, STR analysis transformed forensic science. Its effectiveness has been further increased with the introduction of multiplex PCR, which can analyse multiple STR markers at once.

C. Mitochondrial DNA (mtDNA) Analysis

Introduced in the year 1996, the mitochondrial DNA is inherited exclusively from the mother and exists in large quantities within each cell, thus helpful in situations where nuclear DNA is too sparse or damaged. The mitochondrial genome, which is different from the nuclear genome, is the focus of mtDNA analysis. Given the abundance of mitochondria in cells, mtDNA can be extracted from even tiny or deteriorated samples (like bones, hair, or teeth). In the *State of Tennessee v. Paul Ware*, Paul Ware was found guilty of the rape and killing of a four-year-old girl using mtDNA.[20] In situations where conventional nuclear DNA testing was not feasible, the analysis was essential in identifying a criminal.

D. Y-Chromosome STR Analysis (Y-STR)

The Y chromosome, which is inherited from father to son, is examined by Y-STR analysis. When dealing with mixed DNA samples, this analysis is helpful, especially when separating male and female DNA. To create a DNA profile, PCR is used to examine particular Y chromosome regions that contain brief tandem repeats. When the female victim's DNA is combined with that of the male perpetrator in a sexual assault case, Y-STR analysis is particularly helpful.[21] By comparing DNA recovered from crime scenes with *Albert DeSalvo's* nephew's DNA, Y-STR analysis helped solve the *Boston Strangler* case and establish DeSalvo's involvement. Y-STR analysis was created to overcome the drawbacks of conventional STR analysis in situations involving DNA from several people, particularly mixed samples of males and females. Over time, it has become more refined, enabling the analysis of complex mixtures.[22]

E. Next Generation Sequencing (NGS)

High-throughput sequencing is made possible by NGS, which developed in early 2000's, which enables the quick acquisition of vast amounts of genetic data. Compared to conventional methods, this approach yields more thorough information. Compared to conventional sequencing techniques, NGS entails sequencing a whole genome or particular genetic markers far more quickly. It is able to identify genetic variations such as STRs and *single nucleotide polymorphisms* (SNPs). In 2020's, NGS was applied for the first time in a forensic setting to examine DNA from a double homicide case, yielding more precise genetic data than earlier techniques. Faster and more thorough DNA profiling is now possible thanks to significant advancements in forensic science brought about by NGS technology. More complicated cases, like those with several suspects or inconsistent DNA samples, may be resolved by it.[23]

F. Forensic Genetic Genealogy (FGG)

By tracking down family ties using publicly accessible genetic databases, FGG uses DNA analysis in conjunction with conventional genealogical research to identify individuals. Crime scene DNA is compared to publicly available genetic databases like "23andMe" and "GEDmatch". To find distant relatives and create a family tree that will help identify the suspect, investigators employ genetic genealogy techniques.[24] In 2018, FGG was instrumental in the identification of *Joseph DeAngelo*, the Golden State Killer. After uploading DNA from the crime scene to a genealogy website,

[18] Udogadi Nwawuba Stanley and others, 'Forensic DNA Profiling: Autosomal Short Tandem Repeat as a Prominent Marker in Crime Investigation' (2020) 27 Malaysian Journal of Medical Sciences 22

[19] Sheila Jasanoff, 'The Eye of Everyman: Witnessing DNA in the Simpson Trial' (1998) 28 (5/6) Social Studies of Science 713–40

[20] C. Leland Davis, 'Mitochondrial DNA: State of Tennessee v. Paul Ware' (1998) 1(3) Profile in DNA 6

[21] Denise Syndercombe Court, 'The Y Chromosome and Its Use in Forensic DNA Analysis' (2021) 5 Emerging Topics in Life Sciences 427

[22] Philip Bulman, 'Solving Cold Cases with DNA: The Boston Strangler Case' (2014) 273 NIJ Journal 48

[23] Heena Satam and others, 'Next-Generation Sequencing Technology: Current Trends and Advancements' (2023) 12 Biology 997

[24] Claire L. Glynn, 'Bridging Disciplines to Form a New One: The Emergence of Forensic Genetic Genealogy' (2022) 13 Genes 1381

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investigators were able to match DeAngelo with distant relatives. The most recent development in forensic DNA analysis is FGG. Despite being a relatively new tool, its success has led to its widespread use in cases that were previously unsolvable. It gives law enforcement new options by fusing the strength of DNA analysis with genealogical research.[25]

CASE STUDIES

Cold case investigations, particularly those involving violent crimes, have long represented a significant challenges to law enforcement. These cases, often years or even decades old, had remained unsolved, but through advances in forensic genetic genealogy, reanalysis of old samples or linking previously unconnected crimes, DNA has helped bring justice to victims and closure to families. The cases as discussed hereafter are a testament to the ongoing role that DNA technology will continue to play in criminal investigations worldwide.

A. The Golden State Killer Case

The Golden State Killer, also known as *Joseph DeAngelo*, was responsible for a series of heinous crimes committed across California between 1976 and 1986, including 13 murders, 50 rapes and over 100 burglaries. Despite years of investigation, the identity of the killer remained elusive. DNA evidence collected from multiple crime scenes in California had been tested over the years, but it was not until 2018, that investigators achieved a breakthrough. Using forensic genetic genealogy, law enforcement officials analyzed the DNA from the crime scenes to open-source genealogical databases such as GEDmatch. This innovative approach allowed investigators to trace distant relatives of the perpetrator, eventually identifying him as the Golden State Killer. Joesph was arrested in 2018 at the age of 72. This case exemplifies the power of forensic genetic genealogy is solving cold cases.[26] The success of investigation in the case demonstrated the advances in DNA analysis techniques, while overcoming the challenges posted by decades of unsolved crimes. This case is marked as one of the most high profile instances of forensic genealogy being used to identify a serial criminal in United States of America, showcasing the transformative potential of this method in criminal investigations and raising some debatable concerns regarding individual privacy.[27]

B. The Rhonda Hinson Murder Case

The murder of 15-year-old *Rhonda Hinson* in 1986 remained unsolved for over 20 years. Rhonda was found by the roadside in *North Carolina*, USA, but no suspect was identified. The case was reopened in 2012 upon re-examining DNA evidence taken on Rhonda's body. The process led to the identification of *Donald James Hinton*, a man who was already known to law enforcement through his violent crimes. The DNA collected from the scene of the crime matched Hinton's DNA, leading to his arrest. This case demonstrates the importance of re-examining historical evidence with new DNA analysis techniques. It also demonstrates the importance of collecting 'biological evidence' at crimes, even cold cases where no leads existed. DNA analysis made a huge breakthrough in an investigation that had been dormant for several decades, finally bringing justice to Rhonda Hinson and her family.[28]

C. The Cleveland Strangler Case

Anthony Sowell killed a minimum of 11 women in *Cleveland, Ohio*, between 2007 and 2009. The victim's remains were found in his home, but it was not until Sowell was arrested that DNA connected him with the crimes. DNA evidence obtained from the bodies of the victims was instrumental in connecting Sowell to the killings. The DNA evidence matched Sowell's DNA profile, and he was arrested. The case was cracked when cold case detectives reopened past cases and re-tested evidence using new DNA technology, proving that Sowell was the killer. The Cleveland Strangler case best illustrates the significance of DNA evidence in establishing connections between unrelated cases. By re-analyzing the evidence previously collected through contemporary DNA analytical techniques, detectives were able to connect Sowell to several murders that had previously gone unacknowledged. This particular case is a great illustration of how DNA evidence can solve individual cold cases

[25] Ray A Wickenheiser, 'Forensic Genealogy, Bioethics and the Golden State Killer Case' (2019) 1 Forensic Science International: Synergy 114
[26] William Thorp and Innerst Josh, *The Golden State Killer Case* (Highbridge Company, 2025)
[27] J.V. Chamary, 'How Genetic Genealogy Helped Catch The Golden State Killer' (*Forbes*) <https://www.forbes.com/sites/jvchamary/2020/06/30/genetic-genealogy-golden-state-killer/> accessed 13 May 2025
[28] Julie Mattson, 'The Tragic Murder of Rhonda Hinson' (*Pushing Up Lillies*, 25 December 2024) <https://pushinguplilies.com/the-tragic-murder-of-rhonda-hinson/> accessed 14 May 2025

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while simultaneously revealing serial crimes that were previously overlooked.[29]

D. The Albertville Cold Case

In 1988, the murder of 15-year-old *Jessica O'Grady* of *Albertville, Alabama*, remained unsolved for over two decades. Without DNA evidence at the crime scene, no suspects or leads were available for years. The case was reopened in 2007, when the DNA evidence was reanalyzed using newer techniques. The genetic material recovered at the crime scene was traced to Jason Pruitt, who had a previous criminal history. Pruitt was then arrested, and DNA testing confirmed his link to the murder. This case suggests the importance of reopening unsolved cases and applying modern DNA techniques to historical evidence. Reopening Jessica O'Grady's case shows the potential of technological developments to introduce essential breaks into otherwise stalled cases. It also illustrates the importance of preserving the integrity of DNA evidence to continue to analyze, since new techniques could provide leads otherwise lost.[30]

E. The Phantom Killer Case

In the 1980s, a Swedish woman, was murdered and the crime went unsolved for more than 20 years. Even after semen was found at the scene of the crime, no suspect was discovered. In 2009, Swedish authorities performed a re-examination of the DNA evidence that had been gathered at the scene of the crime. Through sophisticated DNA analysis, they were able to link the evidence to the individual of *Johan Lundstrom*, who had a prior criminal record. Lundstrom was subsequently arrested and found guilty of the murder. The Lundstrom case is an excellent illustration of the need to revisit cold cases through the application of new forensic methods. Furthermore, it illustrates the essential role that DNA evidence plays in cracking cold cases that have been cold for decades, especially when coupled with new forensic technology. The capacity to identify criminals after decades of investigation is proof of the ongoing relevance of DNA evidence in criminal justice.[31]

F. Murders and Sexual Assault of Bogle and Kalitzke

In November 1956, *Lloyd Bogle* and *Patricia Kalitzke's* bodies were discovered in a rural area outside of *Catoosa, Oklahoma*. The victims had been raped and shot. Although initial examinations were conducted, the case remained cold for several decades, and there were no leads or suspects. The case went cold for more than 40 years until DNA analysis in the early 2000s gave a break. DNA extracted from the bodies of the victims was re-analyzed, and forensic analysis in 2008 resulted in a match with the DNA of a man, *Dennis Lynn Wyrick*. Wyrick was already in prison for other unrelated offenses, and DNA analysis confirmed his role in the murders of 1956. This case demonstrates the power of DNA testing in cracking decades-old cases. It demonstrates how modern DNA testing can connect offenders to crimes from decades ago, even in cases where traditional investigation techniques failed.[32]

G. The Esther Gonzalez Murder

The last time *Esther Gonzalez* was seen, she was on foot from where she lived in *Beaumont* to where her sister lived in *Banning, California*. Her body was discovered the next day alongside Highway 243 with signs of sexual assault and blunt trauma. The case sat cold for over forty years. Interviews and a polygraph examination were done in the first investigation of *Lewis Randolph "Randy" Williamson*, the discoverer of the body. Williamson passed the polygraph and was cleared of involvement. The Riverside County Sheriff's Cold Case Homicide Unit reopened the case in 2023. They used a novel investigation method, *forensic genealogy*, to analyze 'semen' samples taken from Gonzalez's body. Semen samples were matched against DNA from Williamson during his 2014 autopsy. The match identified Williamson as the killer. The California Department of Justice verified the match, officially closing the case in 2024. This case is a quintessential example of the crucial role of DNA evidence in solving cold cases. Forensic technology, such as forensic genealogy, has provided law enforcers with new

[29] Ryan Haidet, '"Very Scary People" to Focus Season 6 Premiere on Serial Killer Anthony Sowell: "The Cleveland Strangler"' (*wkyc.com*, 12 December 2024) <https://www.wkyc.com/article/news/local/cleveland/cleveland-strangler-anthony-sowell-serial-killer-very-scary-people-episode-donnie-wahlberg> accessed 14 May 2025

[30] Nadine El-Bawab, 'Suspect in Cold Case Murder Dies by Suicide Days after Submitting DNA: Police' (*ABC News*, 31 July 2024) <https://abcnews.go.com/US/suspect-cold-case-murder-commits-suicide-days-after/story?id=112417313> accessed 14 May 2025

[31] Sean Neumann, 'A Series of Killings Was Pinned on a Mystery Woman. Then the Case Took a Shocking, "Phantom" Turn' (*People.com*, 21 December, 2024) <https://people.com/phantom-of-heilbronn-serial-killer-that-wasnt-germany-dna-mishap-8763448> accessed 15 May 2025

[32] Sharon Pruitt-Young, 'Detectives Just Used DNA To Solve A 1956 Double Homicide. They May Have Made History' *NPR* (12 June 2021) <https://www.npr.org/2021/06/12/1005690930/detectives-just-used-dna-to-solve-a-1956-double-homicide-they-may-have-made-hist> accessed 15 May 2025

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avenues to solve crimes that have remained unsolved for decades. The successful resolution of this case highlights the importance of re-opening old cases through new technologies for the sake of justice.[33]

H. The Murder Case of Nancy Marie Bennallack

Nancy was tragically murdered in 1970, despite the tireless efforts of law enforcement no case was eventually went cold. In 2004, detectives developed a DNA profile from blood evidence at the crime scene. The profile was uploaded into the FBI's CODIS without resulting in any matches. Even after conducting five family searches on the *California Department of Justice* between 2009 and 2021, no potential leads were found. In 2021, the Sacramento County District Attorney's Office was awarded a grant from the BJA's Prosecuting Cold Cases Using DNA program. That funding allowed the use of *forensic genetic genealogy* (FGG), a method which queries public genealogical databases for DNA profiles to identify probable relatives of the perpetrator. The suspect's profile was uploaded into those databases in 2019, and after thorough genealogical analysis, the investigators concluded that *Richard John Davis* was the probable perpetrator. This is the longest-standing cold case murder to be solved in Sacramento County. The use of forensic genetic genealogy, a technique which was previously employed to apprehend the Golden State Killer, demonstrates the changing strength of forensic science to crack cold cases. Though Davis had died, the identification provided closure to the case.[34]

SCIENTIFIC CHALLENGES AND TECHNICAL LIMITATIONS

Revolutionising the forensic scene, DNA evidence provides one of the most potent tools in contemporary criminal investigations by offering a degree of accuracy and precision. Though its use is not without difficulties even if DNA can clear the innocent and condemn the guilty. Ensuring that DNA evidence is used efficiently and fairly in the criminal justice system requires a thorough awareness of its scientific and technical limitations. Although DNA evidence is a significant development in criminal justice, it is not a perfect instrument. The scientific and technical constraints of DNA analysis including contamination, degradation and interpretation issues emphasize the importance of ongoing vigilance and improvement of forensic techniques.

A. Contamination and Degradation of DNA Sample

The possibility of contamination and degradation is among the most important difficulties in relying on DNA evidence. A fragile molecule, DNA is very sensitive to environmental elements including heat, humidity, and sunlight exposure. Biological samples such as blood, hair and saliva can also deteriorate with time, especially under bad circumstances or improper storage. Collection, transport, or storage can compromise the integrity of DNA evidence, therefore making the findings questionable or perhaps court inadmissible. Contamination can also happen if forensic experts ignore rigorous protocols handling evidence or if several samples are processed together. The *O.J. Simpson case*, for instance, drew criticism over evidence mishandling and contamination, which sparked a national discussion on the need of preserving appropriate DNA procedures at all levels of the investigation. Results can be distorted by even tiny DNA traces from unintentional sources, therefore causing wrongful convictions or exonerations. The criminal justice system has to guarantee that rigorous chain-of-custody policies and best practices in evidence handling are followed to preserve the integrity of DNA samples all through the inquiry and trial process, therefore minimising these dangers.[35]

B. Interpretation and Statistical Limitation

Although many people think DNA evidence is accurate, the reading of DNA profiles is not always readily apparent. To assess the probability that a certain DNA sample belongs to a particular person, forensic professionals have to depend on sophisticated statistical models. The quality of the sample, the number of markers employed for comparison and the general population database used for reference all affect the accuracy of these models. Results can sometimes be unclear or inconclusive,

[33] Marina Dunbar, 'DNA Links Man Cleared by Polygraph to 1979 Killing of California Teenage Girl' *The Guardian* (25 November 2024) <https://www.theguardian.com/us-news/2024/nov/25/california-1979-murder-suspect> accessed 15 May 2025

[34] Cecilio Padilla, 'Genetic Genealogy Identifies Suspect in Brutal 1970 Killing of Sacramento-Area Woman', *CBS Sacramento* (10 August 2022) <https://www.cbsnews.com/sacramento/news/nancy-bennallack-sacramento-murder-cold-case-genetic-genealogy-suspect-id/> accessed 15 May 2025

[35] Lina Bhoyar L, Palash Mehar P and Krishnadutt Chavali, 'An Overview of DNA Degradation and Its Implications in Forensic Caseworks' (2024) 14 Egyptian Journal of Forensic Sciences 15

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especially in mixtures containing DNA from several people. Highly sophisticated analysis is required to separate several DNA sources in a single sample such as in sexual assault cases and even then, it might be impossible to definitively establish the origin of the DNA. Moreover, several elements including sample quality, pollution, and natural diversity in human populations affect the reading of DNA findings. Though not free of human error, DNA testing provides great accuracy. Errors in analysis, such as *mislabelling samples*, *erroneous reading of findings* or *technical problems* with laboratory equipment, can cause 'misidentifications' and 'wrongful convictions'. Results may also be less reliable if one relies on a small number of genetic markers, particularly when handling degraded or partial samples.[36]

C. Limited Applicability

Though widely used in criminal probes, DNA evidence is not always accessible or relevant in all situations. Many offences leave no DNA evidence whatsoever. DNA analysis might not be a pertinent investigative tool, for instance, in cases involving financial fraud, particular kinds of assault, or crimes committed in public areas where no physical evidence is gathered. Furthermore, not every crime scene generates enough DNA for study. Results might not be conclusive in situations where only tiny or degraded DNA samples are found. DNA evidence does not prove the innocence of a suspect even in cases where it is lacking, despite its availability. DNA is only one component of the puzzle; its presence or absence should be evaluated together with other types of evidence including witness testimony, forensic analysis, and circumstantial evidence. The legal system has to be fair in its approach to evidence; it should not too depend on DNA as the only deciding factor for guilt or innocence.[37]

D. Issue of Familial DNA and Close Relatives

Usually regarded as a way to identify people, DNA profiling relies on their own genetic composition. Familial DNA analysis the technique of finding relatives of a suspect depending on shared genetic markers raises significant ethical and legal questions, though. While it opens the door to implicating people simply connected to the offender, familial DNA testing can be quite successful in finding suspects when a direct DNA match is unavailable. DNA testing, for instance, could find a suspect's relatives but not offer clear proof connecting the person to the site of the crime. This begs issues regarding the application of family DNA in criminal probes and the possibility of erroneous identification depending only on genetic ties. To stop the abuse of family DNA profiling and guarantee its use only when suitable and justified, legal and ethical protections have to be in place.[38]

LEGAL AND PROCEDURAL CONCERNS

While DNA evidence is certainly strong and changing, its application in the criminal justice system raises legal and procedural issues that must be considered. Chain of custody problems, access to post-conviction DNA evidence, admissibility criteria, privacy issues and bias in DNA databases all present major obstacles that legal reforms and thorough judicial oversight must address.

A. Chain of Custody

A basic idea in the management of evidence in criminal cases is the chain of custody. It describes the recorded procedure tracking the handling, storage, and transportation of evidence from the crime scene to the courtroom. A break or flaw in the chain of custody for DNA evidence might raise doubts about the quality of the sample and its examination. Any questions regarding the handling of the evidence could make it unfit for use in court. Recent events still draw attention to the importance of chain of custody.[39] In *Jones v. R* [2020] EWCA Crim 1021, for instance, the defendant questioned the acceptability of DNA evidence since the prosecution did not prove a consistent chain of custody from collection to analysis. The court decided that although the DNA evidence could still be allowed, the lack of appropriate sample handling documentation would be considered when assessing its reliability.

B. Post-Conviction Access to DNA Evidence

Post-conviction access to DNA evidence is another important problem. Wrongful convictions are a major worry, particularly

[36] National Research Council, 'Statistical Issues', *The Evaluation of Forensic DNA Evidence* (National Academies Press, US, 1996)

[37] Ofomata C. Maxwell and Chukwudum C. Prince, 'Application of DNA Forensic Evidence in Criminal Justice System' (2025) X International Journal of Research and Innovation in Applied Science 312

[38] Rana M. Mateen and others, 'Familial DNA Analysis and Criminal Investigation: Usage, Downsides and Privacy Concerns' (2021) 318 Forensic Science International 110576

[39] Ashish Badiye,Neeti Kapoor and Ritesh G. Menezes, *Chain of Custody* (StatPearls Publishing 2025)

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when fresh DNA evidence comes available following a conviction. In certain areas, people trying to establish their innocence using DNA testing might run into legal obstacles including protracted waits or perhaps total denial of access to evidence. One of the most important legal cases in this field was *Osborne* case of 2009[40], in which the U.S. Supreme Court held there is no constitutional right to access DNA evidence post-conviction. The court's decision practically restricted people's use of DNA evidence to contest their convictions unless the state allowed it under its own will. This ruling ignited a continuous discussion on the equity of the criminal justice system and the rights of people to challenge their convictions in light of fresh evidence. On the other hand, certain states have passed legislation granting prisoners access to DNA testing. For instance, the *Alabama Court of Criminal Appeals* permitted a convicted guy to obtain DNA evidence from his case, therefore exonerating him after 20 years of wrongful incarceration.[41] Emphasising the need for a fairer criminal justice system, this case underlines the continuous drive for legislative reform to enable more access to DNA evidence.

C. Admissibility

Different elements can call into question DNA evidence's inclusion, therefore its admissibility in court is not always assured. Especially with regard to its interpretation and the techniques employed for analysis, forensic DNA evidence is frequently questioned about its dependability. Before it can be applied in a trial, courts have to decide whether the evidence satisfies particular criteria. The U.S. Supreme Court set the principles[42], which states that scientific evidence must be trustworthy and founded on techniques generally accepted in the scientific community. To be admissible, DNA evidence has to satisfy these exacting criteria. The use of this criterion, meanwhile, may change from situation to case. Citing problems in the DNA sample analysis technique, a judge rejected DNA evidence since the expert testimony failed to satisfy Daubert's reliability criteria.[43] Courts also struggle to make sure juries see DNA evidence clearly and understandably presented. For those who are not professionals, the complexity of DNA testing might be confusing. The court in 2019 permitted expert testimony on DNA analysis but underlined the jury's need for obvious and straightforward explanations. The defence claimed successfully that the jury was confused by the DNA expert's excessively technical language, which caused some testimony to be excluded.[44]

D. Ethical Concerns Regarding Privacy

Serious ethical and privacy issues are also brought up by the gathering, processing, and storage of DNA samples. The possibility of abuse or overreach by law enforcement increases with the size of DNA databases. For example, the use of familial DNA testing can identify people who are related to a suspect but may not have been directly involved in a crime. This presents moral dilemmas regarding the extent of genetic data collection and the possibility of falsely accusing innocent people.[45] The European Court of Human Rights rendered a landmark decision in the 2011 case[46], in the United Kingdom, concluded that the retention of DNA samples from people who had not been found guilty of a crime was a violation of the European Convention on Human Rights. The court addressed concerns about needless surveillance and privacy violations by ruling that genetic data of people who have not been convicted should not be stored in DNA databases. In order to guarantee that DNA databases are used morally and in a way that respects people's right to privacy, this decision was a turning point. Similar discussions have been triggered in the US by the growth of DNA databases. The U.S. Supreme Court affirmed the constitutionality of taking DNA samples from people who have been arrested for serious crimes, even if they have not been found guilty, in the 2013 judgment[47], Calls for reform and stronger privacy protections have been triggered by this ruling, which has raised concerns about the mass collection of DNA and the possibility of discrimination based on genetic information.

E. DNA Data Bias

The possibility of racial and socioeconomic bias in DNA databases presents another difficulty for the legal and procedural application of DNA evidence. Minority groups, especially African

[40] *District Attorney's Office v. Osborne* 557 U.S. 52 (2009)
[41] *Ex Parte Larry Green* (Ala. Dec. 3, 2021)
[42] *Daubert Standard in Daubert v. Merrell Dow Pharmaceuticals Inc.*, 509 U.S. 579 (1993)
[43] *People v. Acevedo*, 84 A.D.3d 1390 (2021)
[44] *State v. Clark*, Docket No. 45062 (2019)
[45] Erik Ortiz, 'Golden State Killer Suspect's Capture Sparks DNA Site Privacy Fears' (*NBC News*, 27 April 2018) <https://www.nbcnews.com/news/us-news/golden-state-killer-suspect-s-capture-sparks-dna-site-privacy-n869661> accessed 15 May 2025
[46] *R (GC) v. Commissioner of Police of the Metropolis*, [2011] UKSC 21
[47] *Maryland v. King*, 569 U.S. 435 (2013)

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American and Hispanic communities, are over-represented in DNA databases, according to research. This raises questions regarding racial profiling and discrimination since it may result in biased targeting and heightened surveillance of members of these communities. The possibility of bias in DNA database searches was brought to light in a 2019 report by the *National Institute of Justice* (NIJ)[48], which pointed out that people from particular racial or ethnic groups are more likely to be in the system because of higher arrest rates. This systemic bias has the potential to worsen already-existing disparities in the criminal justice system and result in erroneous convictions. To guarantee that DNA databases are used equitably and without discrimination, the report urges greater oversight and openness in their operations.[49]

CONCLUSION & SUGGESTIONS

Unquestionably, the use of cutting-edge DNA analysis techniques has transformed cold case investigations by providing forensic specialists and law enforcement with new ways to solve cases that were previously unsolvable. The ability to extract essential genetic evidence from damaged or sparse samples has been greatly improved by the growing sophistication of DNA profiling, including the improvement of techniques like Y-STR and Short Tandem Repeat (STR) analysis. Even in situations where physical evidence is limited or tainted, these developments enable a more thorough identification of suspects. Notably, the use of genealogical databases to conduct Investigative Genetic Genealogy (IGG) has become a ground-breaking technique for identifying criminals connected to cold cases. This approach, which has been used to resolve well-known cases like the Golden State Killer investigation, demonstrates the revolutionary potential of DNA analysis when paired with genetic information from families.

In the past 5 years the case resolutions have been accelerated by the use of Artificial Intelligence and Machine Learning in the forensic analysis of genetic data, which has improved investigation speed and accuracy and promoted a more effective forensic procedure. The efficiency of DNA technology in cold case resolution has been further enhanced by the partnership between private forensic labs and public law enforcement organisations. These collaborations make use of cutting-edge forensic technologies, guaranteeing that cases that were previously unsolvable are re-examined with new insights and more precise techniques. Furthermore, the development of environmental and spatial DNA analysis shows promise for broadening the scope of available evidence, especially in situations involving crime scenes that are challenging to reach.

Although, we have not yet arrived at a point where DNA evidence can be considered infallible, even if its accuracy may be growing daily due to scientific advancements making it increasingly trustworthy. It is therefore impossible to claim that the lack of DNA evidence would result in a negative conclusion about a party, particularly when there is other strong and trustworthy evidence in support of that party. Legal systems have to change to handle the ethical issues and guarantee proper use of DNA evidence inside the criminal justice system. Scientific progress calls for corresponding development of the systems depending on it, with close regard to justice, fairness, and accuracy. The criminal justice system can maintain its goal of providing justice without infringing on people's rights only by a sophisticated knowledge and ethical use of DNA evidence.

Courts have to keep changing their approach to DNA evidence to make sure it is applied fairly and in a way that safeguards people's rights while supporting the search of truth in the criminal justice system. To create standards and procedures that preserve the integrity of DNA evidence, legal experts, forensic scientists, and legislators have to work together, therefore transforming it into a more consistent and fair weapon in the battle for justice.

Furthermore, a coordinated and cooperative approach among international law enforcement agencies is required due to the international aspect of contemporary cold case investigations, which is enhanced by DNA evidence and cross-border data sharing. In order to resolve cases that span multiple jurisdictions and guarantee that offenders are brought to justice regardless of geographic boundaries, international cooperation is essential. To sum up, DNA technology is at the forefront of criminal justice

[48] Robert C. Davis, Carl J. Jensen and Karin Kitchens, 'Cold Case Investigations: An Analysis of Current Practices and Factors Associated with Successful Outcomes', *National Institute of Justice* 237971 (October 2011)

[49] Sakib T. Rishan, Richard J. Kline and Md Saydur Rahman, 'Applications of Environmental DNA (eDNA) to Detect Subterranean and Aquatic Invasive Species: A Critical Review on the Challenges and Limitations of eDNA Metabarcoding' (2023) 12 Environmental Advances 100370

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and has the unmatched ability to solve unsolved cases and right historical wrongs. However, the ethical and legal frameworks governing its use must also change as technology does. The full potential of DNA analysis in the pursuit of justice can only be achieved by a diligent and cooperative approach that combines scientific innovation with strict legal oversight.