ISSN-0971-720X (Print) • ISSN-0973-1283 (Electronic)

Volume 25 Number 4 October-December 2025

Medico-Legal Update

An International Journal

www.medicolegalupdate.org

Medico-Legal Update

E-mail: medicolegalupdate@gmail.com

Medico Legal Update is a scientific journal which brings latest knowledge regarding changing medico legal scenario to its readers. The journal caters to specialties of Forensic Medicine, Forensic Science, DNA fingerprinting, Toxicology, Environmental hazards, Sexual Medicine etc. The journal has been assigned international standard serial number **(ISSN) 0971-720X.** The journal is registered with Registrar of Newspaper for India vide registration numbers 63757/96 under Press and Registration of Books act, 1867. Medico legal update is a half yearly peer reviewed journal. The journal has also been assigned **E-ISSN 0973-1283 (Electronic version)**. The first issue of the journal was published in 1996.

Website: www.medicolegalupdate.org

Published at

Institute of Medico-legal Publications

Logix Office Tower, Unit No. 1704, Logix City Centre Mall,
Sector- 32, Noida - 201 301 (Uttar Pradesh)

Medico-Legal Update

Vol 25 No. 4, October-December 2025

Contents

Review Article

DOI: https://doi.org/10.37506/t45rc165

Gender-Based Variations in Crime: Case Studies and Data Analy

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How to cite this article: Pratheesh, Anisha Anant Kudaskar, Vaishnavi Vivek Sawant, ThejuKumar C. Gender-Based Variations in Crime: Case Studies and Data Analy. Medico-Legal Update / Vol 25 No. 4, October - December 2025

Abstract

This study examines gender differences in crime, a long-standing area of interest within sociology, criminology, psychology, and law. Consistent global patterns reveal that men commit more crimes, particularly violent offenses, than women, though gender also shapes victimization experiences and justice system responses. By analysing statistical trends, types of crimes associated with each gender, and the underlying social, cultural, and biological factors, this research highlights the complex interplay influencing criminal behaviour.In addition to addressing problems of traditional criminological theories, this research critically reviews important theoretical frameworks that explain gender variations in criminal behaviour. It investigates how gender norms or gender stereotypes, cultural expectations, and institutional practices shape outcomes within the justice system. Learning more about these elements is crucial for crafting effective crime prevention strategies, implementing gender-sensitive policies, and ensuring fair treatment across the criminal justice process. Ultimately, the study adds to broader conversations about social justice, gender equity, and the creation of more inclusive and just societies.The findings underscore the persistent gender gap in criminal behavior, shaped by complex social, cultural, and structural factors, and highlight the need for gender-responsive policies to promote fairness and equity within the justice system.

Introduction

Crime has long been a subject of sociological inquiry, offering insights into societal structures, power dynamics, and cultural norms. One of the most consistent patterns in criminology is the disparity in crime rates between men and women. Historically, men have committed more crimes, particularly violent ones, across various societies and time periods. Understanding gender differences in crime involves analysing not only statistical trends but also the underlying social, cultural, and biological factors. This paper indulgesexploring gender imbalances in criminal activity by examining global statistical trends, the types of crimes committed by each gender, theoretical explanations, critiques of existing theories, and the implications for criminal justice policies[1].

Gender has long been recognized as a significant factor in understanding crime dynamics, with research consistently demonstrating differences in criminal behaviour, victimization experiences, and justice system responses based on gender. The study of gender and crime intersects multiple disciplines,

Submission: Jul 15, 2025 **Revision:** September 9, 2025 **Published date: September 25,2025**

including sociology, criminology, psychology, and law, offering valuable insights into the complex interplay of biological, social, and cultural factors shaping individuals' involvement in criminal activities and their interactions with the criminal justice system. This research seeks to explore the nuanced relationship between gender and crime, aiming to shed light on the underlying mechanisms driving gender disparities in criminal behaviour and justice outcomes. By examining various theoretical perspectives and empirical evidence, this study seeks to provide a comprehensive understanding of how gender influences patterns of offending, victimization, and legal processing. Understanding gendered patterns of crime is essential for developing effective crime prevention strategies, designing gender-responsive policies, and promoting equitable treatment within the criminal justice system[2].

Gender disparities in criminal behavior have been extensively examined over the years in disciplines such as sociology, criminology, psychology, and law. Studies globally indicate that men are more prone to engage in criminal activities, particularly violent crimes, while women tend to commit fewer offenses and often partake in non-violent or financial crimes. In addition to these variations in crime perpetrators, gender influences how individuals experience victimization and the treatment they receive from the justice system. Understanding these distinctions is crucial for developing equitable policies that address the needs of all individuals and guarantee fairness for every gender.

In India, the National Crime Records Bureau (NCRB) offers official statistics on crime, displaying patterns and categories of offenses throughout the nation. Recent reports indicate a rise in offenses against women, including domestic abuse, sexual violence, and human trafficking. Although numerous incidents may remain unnoticed because of social stigma and various obstacles, these figures indicate that women continue to be at risk of gender-based violence. Data also indicates that men are primarily engaged in violent crimes such as murder, robbery, and assault. Social, cultural, and economic factors influence these trends, shaping gender roles and behaviors within Indian society[3].

This research seeks to examine the disparities between males and females in criminal behavior in India by analyzing crime data and the societal and cultural factors contributing to these differences. It merges official statistics with an examination of gender roles, stereotypes, and biases within the system to enhance the understanding of how gender influences crime and justice. The aim is to assist in creating improved crime prevention strategies and reforms that promote equality and justice within India's criminal justice system.

The scope of gender and crime is vast and multifaceted, encompassing a range of topics that explore the relationship between gender dynamics and various aspects of criminal behaviour, victimization, and the criminal justice system. Here's a more detailed breakdown of its scope:

1. **Gendered Patterns of Offending:** This involves examining the differences in the types of crimes committed by men and women, as well as the factors that contribute to these gender disparities in offending rates. Researchers analyse how societal expectations, gender socialization, and power structures influence individual involvement in criminal behaviour.

2. **Gender-Based Violence:** Gender and crime research extensively explores forms of violence that disproportionately affect individuals based on their gender, such as domestic violence, sexual assault, honour killings, and human trafficking. Understanding the root causes, prevalence, and consequences of gender-based violence is a significant aspect of this area of study.

3. **Victimization and Gender:** Researchers investigate how gender influences individuals' experiences as victims of crime. This involves analyzing the types of crimes that men and women are more likely to experience or commit, as well as how society responds to victims differently based on gender—for example, through victim blaming or skepticism toward their accounts.

4. **Gender Bias in the Criminal Justice System:** Gender intersects with various stages of the criminal justice process, including arrest, prosecution, sentencing, and incarceration.

5. **Intersectionality:** Intersectional approaches are crucial in understanding how gender intersects with other social identities, such as race, ethnicity, class, sexuality, and disability, to shape individuals' experiences of crime and the criminal justice system. Researchers examine how the intersection of these identities shapes distinct experiences of victimization, offending, and interactions with the criminal justice system[4].

Statistical Trends in Gender and Crime

Globally, men commit a disproportionate share of crimes. According to the Bureau of Justice Statistics (BJS, 2020), males account for approximately 73% of all arrests in the United States. In violent crimes such as homicide, men represent over 90% of offenders (FBI Uniform Crime Reporting, 2019). Internationally, similar patterns are observed. The United Nations Office on Drugs and Crime (UNODC, 2019) reports that men account for about 80-90% of homicide perpetrators worldwide, with slight regional variations. In property crimes and non-violent offenses, women's involvement is relatively higher, though still lower than men's.

Women's participation in crimes like fraud, embezzlement, and drug offenses has shown a slight increase over the past few decades. In the United Kingdom, for instance, the Ministry of Justice (2020) reported that women represented approximately 25% of all prosecutions, with notable involvement in theft and fraud cases. These trends indicate a slow but observable shift in gender patterns, although the gender gap remains significant[5].

Types of Crime by Gender

Types of crimes committed often reflect gendered socialization and opportunities:

- **Violent Crime:** Men dominate in offenses requiring physical aggression, such as homicide, robbery, and aggravated assault. Sociological theories suggest that these behaviours are linked to traditional notions of masculinity emphasizing dominance, strength, and risk-taking (Messerschmidt, 1993).
- **Property and Economic Crimes:** Women are more involved in crimes like shoplifting, welfare fraud, and embezzlement. These offenses often align with economic survival strategies, especially among marginalized women (Daly, 1994).
- **White-Collar and Organized Crime:** Men still predominate in white-collar crimes, though women's participation has grown with their increased presence in professional sectors. In organized crime, women's roles have traditionally been supportive, but there are cases of women leading drug trafficking operations and gangs.
- **Cybercrime:** Emerging trends show that both genders are participating in cybercrime, though men still dominate hacking and large-scale cyberattacks, women are more involved in online fraud and scams.
- **Terrorism:** Although men constitute the majority of terrorists, women in-volved in extremist activities has increased, particularly in supporting roles and propaganda dissemination[6].

Methodology

Aim

The aim of this research is to identify the gender-based differences in criminal behaviour and victimization, and to explore how these differences are influenced by social, cultural, and institutional factors. The study also intends toanalyze statistical crime trends across genders, critically evaluate theoretical frameworks explaining gendered offending, and explore the impact of gender norms and stereotypes on justice system outcomes. Ultimately, the research aims to contribute to the development of more equitable and gender-responsive criminal justice policies.

Procedure

This research followed a structured multi-phase procedure to ensure thorough and credible analysis:

Data Collection

Quantitative data on crime rates, types of offenses, and victim demographics were gathered from international databases such as UNODC, WHO, and national statistics bureaus (e.g., FBI, ONS).

Academic sources, including peer-reviewed journal articles, books, and official reports, were collected to support theoretical and contextual analysis.

Literature Review

A systematic review of literature was conducted to identify and synthesize major theoretical perspectives, including classical, positivist, feminist, and contemporary criminological theories.

Key critiques of traditional models and their limitations in explaining female criminality were examined.

Data Analysis

Quantitative data were analysed using descriptive statistical techniques to identify trends and compare male and female offending and victimization patterns across time and geography.

Thematic content analysis was employed to examine qualitative data, such as case studies, court judgments, and media reports. NVivo software was used for coding to identify recurring themes related to gender bias, cultural perceptions, and institutional reactions.

Synthesis and Interpretation

The findings from both quantitative and qualitative analyses were integrated to provide a comprehensive interpretation of how gender influences criminal behavior and justice outcomes.

The results were discussed in relation to existing theories and policy implications.

Ethical Considerations

Only publicly accessible and ethically sourced secondary data were used. Full citation and academic integrity were maintained throughout.

Data Analysis

Crime Statistics

According to the National Crime Records Bureau (NCRB) report for 2022, a sum of 4,45,256 cases of crimes against women continued to be reported across India. This represents a 4% increase from the previous year, reflecting a continuing rise in gender-based violence. The classification of these crimes is as follows:

- Crueltybyhusband or his relatives: 31.4%. Registered under Section 498A of the Indian Penal Code, remains the mostfrequently reported crime against women. It encompasses both physical and emotional abuse within the household, often linked to dowry demands and patriarchal control.
- Kidnapping and abduction of women: 19.2%. Many cases in this category involve forced marriages, elopement, or trafficking for commercial sexual exploitation or domestic labor. The figures highlight the vulnerability of women, particularly those from rural or economically weaker sections.
- Assault on women with intent to outrage her modesty: 18.7%. Crime under this includes sexual harassment, groping, stalking, and other forms of public or private assault. It reflects prevailing societal attitudes that condone or normalize the violation of women's bodily autonomy.
- Rape: 7.1%. While this percentage may seem relatively low, it is important to recognize that rape is significantly under-reported due to fear of stigma, retaliation, and inadequate support systems. These incidentshighlight the severe threat posed to women's safety across social settings.
- Other crimes: The remaining percentage consist of dowry deaths, cyberstalking, acid attacks, voyeurism, and human trafficking. Though reported less frequently, these crimes often involve long-term psychological and physical harm.

These statistics reveal highlight that a substantial portion of violence against women occurs within the domestic sphere or are rooted in gender-based discrimination. The data calls attention to the ongoing need for legal reform, gender sensitization, and stronger protective mechanisms[7].

Gender and Crime Rates

Research and law enforcement data reveal a class gender gap in both offending and victimization patterns.

Men are disproportionately responsible for violent crimes such as murder, armed robbery, aggravated assault, gang violence, and sexual offenses. This trend is often linked to cultural constructions of masculinity that associate male identity with power, aggression, and dominance. Contributing factors may include unemployment, lack of education, peer influence, and substance abuse.

On other hand, women are more frequently to be victims of crimes that reflect systemic gender inequalities, such as domestic abuse, sexual assault, dowry-related violence, and trafficking. These crimes are frequently unreported due to fear, social stigma, a lack of financial independence, or distrust in the criminal justice system. Women from marginalized communities, such as Dalits, Adivasis, or LGBTQ+ individuals, are more vulnerable.

When women commit crimes, they are more likely to be involvein non-violent or economically driven offenses such as petty theft, fraud, or drug couriering. In many cases, such involvement arises from poverty, exploitation, or coercion by male partners. Women are also less likely to hold leadership roles in criminal enterprises, reflecting broader structural inequalities.

The different patterns of criminal behavior and victimization along gender lines also influence public perception and judicial outcomes. Few examples, female offenders are often judged more harshly when their actions contradict expected gender roles, especially in cases involving child neglect or violent crimes. Meanwhile, leniency in sentencing for women in some contexts may be based more on stereotypical views of women as passive or dependent rather than a genuine understanding of their circumstances.

Overall, the analysis reveals that gender significantly influences how shaping the experiences of individuals within the criminal justice system—as victims, offenders, and as subjects of legal and social judgment. These findings underline the need for gender-responsive policies and reforms that acknowledge the complex social realities behind crime and justice in India[8].

Gender Bias in the Criminal Justice System

Gender -based biases within the criminal justice system significantly impact on outcomes for male and female offenders. Women often receive more lenient sentences for non-violent crimes, particularly if they conform to traditional gender roles. Conversely, women who commit violent crimes or deviate from gender expectations may face harsher judgments. These biases reflect broader societal attitudes toward gender and morality.

Recent Trends and Implications

Recent data show a slight narrowing of the gender gap in crime, particularly in non-violent offenses. Several factors contributing to this trend include:

- **Evolving Gender Roles:**As more women enter the workforce and participate in public life, their exposure to both legal and illegal opportunities have increased
- **Economic Pressures:** Economic downturns and widening income inequality may push more women into economically motivated crimes.
- **Policy Changes:**Stricter crime policies and shifts in law enforcement practices have led to more arrests for minor offences.

Despite these trends, violent crime remains predominantly male. Cultural norms around masculinity, systemic inequalities, and structural barriers continue to perpetuate this disparity[9].

Case Study: Karen Matthews and the Kidnapping of Shannon Matthews (2008)

The case of Karen Matthews stands out in contemporary British criminal history, not only for

the crime itself but for the media and public reaction it provoked—deeply rooted in gender stereotypes and class biases. In February 2008, Karen Matthews, a 32-year-old mother from Dewsbury, West Yorkshire, reported her 9-year-old daughter Shannon Matthews missing after school. The case immediately gained national attention, especially given its proximity in time to the well-known disappearance of Madeleine McCann.

A massive and costly police operation followed, involving over 300 officers and an expenditure exceeding £3 million. Public sympathy grew as media coverage painted Karen Matthews as a distraught and helpless mother. However, the narrative shifted dramatically after Shannon was found alive 24 days later, hidden in a divan bed at the home of Michael Donovan—Karen's boyfriend's uncle. Investigations revealed that Matthews had conspired with Donovan to stage the kidnapping, intending to later "discover" Shannon and claim the £50,000 reward money offered by a local newspaper.

From a criminological standpoint, the Matthews case is significant not only for the crime itself, but also for what it reveals about how female offenders, particularly mothers, are treated in the criminal justice system and media discourse. Karen Matthews was vilified as both a criminal and a failed mother. The crime was framed as a betrayal of her maternal duties, which violated the deeply held societal ideal of motherhood as inherently nurturing, protective, and selfless.

Unlike many male offenders whose crimes may be assessed primarily in terms of motive and criminal behavior, Matthews was judged through a moral lens that emphasized her perceived shortcomings as a woman and a mother. Tabloid headlines branded her "Britain's Worst Mum," highlighting her working-class background, poor parenting record, multiple children by different fathers, and perceived lack of intelligence. This personalized and sensationalist coverage amplified the social outrage and may have contributed to the severity of her sentence. In December 2008, she was convicted of kidnapping, false imprisonment, and perverting the course of justice and sentenced to eight years in prison. She served approximately half of this sentence before being released on license.

The Matthews case reveals how **gendered and class-based narratives** intersect in the public and legal responses to female offenders. Her actions, while criminal, were uniquely pathologized because they conflicted with the dominant ideals of femininity and motherhood. In contrast, male criminals committing comparable or worse offenses often face public scrutiny for their actions alone, not their personal failings in relation to gendered roles.

Furthermore, the case illustrates how **media representations** can shape societal perceptions and potentially influence judicial processes. The portrayal of Matthews as manipulative, unintelligent, and morally deviant contributed to a widespread belief that she deserved a harsh punishment—not just for the crime, but for being an unfit mother and a 'bad woman'.

It highlights the need for a justice system that recognizes the structural, psychological, and socio-economic dimensions of crime—especially when addressing female offenders whose actions do not conform to traditional gender norms. Matthews' case underscores how criminality in women is often interpreted as an aberration from expected womanhood[10].

Conclusion

Understanding gender differences in crime requires a multifaceted approach that considers biological, social, cultural, and structural factors. Men consistently outnumber women in criminal activities, especially violent crimes, although women's involvement in non-violent and economic crimes has increased. Future research should focus on the evolving nature of gender roles and how technological, economic, and political changes influence criminal behaviour.

In criminological terms, this case serves as a clear example of how gendered expectations influence both the perception and treatment of offenders. Policy implications include the need for gender-responsive interventions that address the specific

needs and circumstances of female offenders, reforming sentencing practices to eliminate gender biases, and developing prevention programs that challenge harmful gender norms. A comprehensive understanding of gender and crime not only enhances criminological theory but also promotes a more equitable and effective criminal justice system.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

Ethical Clearance: Not required as study does not employ live subjects

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Review Article DOI: https://doi.org/10.37506/wh6f6c55

Ear Prints in Forensic Science: A Unique Tool for Criminal Identification

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How to cite this article: Maryam Qidwai, Rakesh Mia, Piyush Kant Mishra. Ear Prints in Forensic Science: A Unique Tool for Criminal Identification. Medico-Legal Update / Vol 25 No. 4, October - December 2025

Abstract

This article focuses on the importance of ear prints in forensic science and how it has proved to be an invaluable tool in criminal investigation over time. Ear print analysis is an emerging forensic technique for criminal identification, leveraging unique two-dimensional ear impressions found at crime scenes. Similar to fingerprints, ear prints are distinct biometric identifiers, potentially more resistant to manipulation. Their individuality stems from complex ear morphology, including features like the helix and earlobe. Collected via methods akin to fingerprinting, analysis involves superposition and digital comparison. While useful for suspect identification and height estimation, ear prints face challenges in court admissibility due to reproducibility issues, subjective analysis, and lack of standardized protocols. Ongoing research aims to enhance their reliability and acceptance as a valuable corroborative tool in forensic investigations, necessitating further validation for broader legal use.

Introduction

As forensic science develops further, new techniques for criminal identification are introduced. Ear print analysis is one such technique that has received attention as a possible forensic tool for identifying suspects at crime scenes. An exact replica two-dimensional model of the ear that has been in contact with a particular surface is called an ear print, and most of the time, offenders leave their ear prints at the scene of the crime[1].

Forensic identification in many criminal instances is accomplished using ear print analysis. Because they share characteristics, researchers have based their studies on ear print analysis in a manner similar to fingerprint analysis. The techniques used to secure ear prints may not differ significantly from those used to lift fingerprints because, for example, both fingerprints and ear prints are obtained from crime scenes and subsequently compared to a database of prints taken from suspects in the crime. Criminals can easily manipulate the fingerprints of innocent individuals, but they may not be able to do the same with ear prints. As a result, ear prints play a larger part in prosecuting offenders, and their presence at crime scenes needs to be made widely known to obtain just convictions and bring about justice. Comparable to fingerprints, each person's ear print is distinct and can be utilised as biometric proof. Ear prints are a powerful but underutilised method of forensic identification since they are more difficult to alter than fingerprints[2].

Submission: July 23, 2025 **Revision:** August 24, 2025 **Published date: September 25,2025**

Ear Morphology

The ear has a unique anatomical layout.

- Outer rim, helix and earlobe are mainly responsible for the external ear morphology. There is also an inner helix, often known as an antihelix, that generally aligns parallel to the outer helix but splits into two distinct branches at the top.
- The concha, which gets its name from its shell-like appearance, has superior and lateral aspects made up of the inner helix and the inferior branch of these two branches. Anatomically, the lower portion of the concha joins the easily identifiable intertragic notch. It's also critical to pay attention to the helix's crus, or the intersection of the helix with the lower branch of the antihelix.
- When an ear is rubbed against a surface, the crux of the helix dependably leaves an impression despite its varied morphologies. The anatomical characteristic that dictates the external ear's shape is the helix rim. There is much variation in the rim's morphology. Each person has a different starting or ending point for unwinding. An important factor in the identification process is the helix rim's inside edges.
- Helix, antihelix, tragus, and antitragus imprints are frequently seen in ear prints. The latter two substances could appear as separate patches or as an expansion of the intertragic notch shape.

The external ear's uniqueness is responsible for individualisation. Developments in forensic science have made it possible to use morphological characteristics and prints of various body parts to determine a person's identification[3].

Several morphological characteristics are studied and taken into consideration while examining an ear print. Different types and shapes have been studied along with variations in helix, shape, size, form of the earlobe, Darwin's tubercles, etc.

- **Helix & Antihelix:** The curved ridges of the outer ear.
- **Lobule (Earlobe):** Shape (attached or free) varies among individuals.
- **Tragus & Antitragus:** Small cartilage projections near the ear canal.
- **Concha:** The hollow near the ear opening.
- **Scars, Deformities, or Piercings:** Unique identifying marks.
- **Ear Shapes**:
  - Oval type: The print's width, measured at tragus level, is less than half ear length, and its side margins are rounded. As it happens, it is the most common form type.
  - Circular type: Edges of the prints are rounded. At tragus level, the impression's width is greater than half of its length.
  - Triangular type: It shows the larger helix of the triangular edge of the impression.
  - Rectangular type: has a pointed helix with a relatively rectangular border.
- **Ear Lobes**:
  - Joined (Attached) earlobe: The Earlobe is jointed at the side of the skull.
  - Detached (Free) earlobe**:** Below the attachment point, the earlobe is free to hang. Partially attached earlobe: The earlobe is neither fully fused to the cheek nor completely free hanging[4].

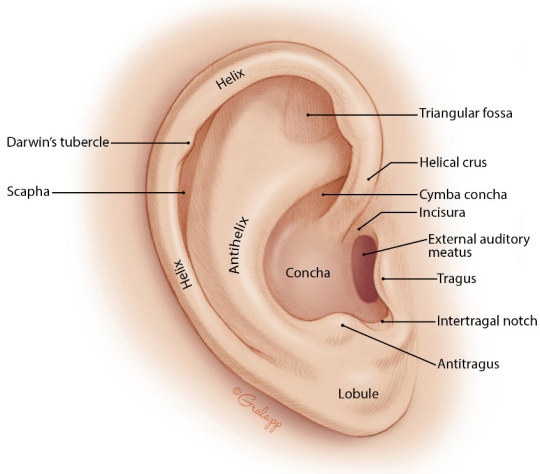

Fig. Morphology of Human Ear[5]

Ear Print and It's Presence on Crime Scene

When ear secretions come into touch with surfaces like walls or glass, a latent ear print is formed. Wax, desquamation, and hormones are among the factors that regulate the secretions. A clear latent ear print may develop when several secretions are present. The regions which are most prominently present on the ear print are tragus, antitragus, helix, and antihelix.

The most frequent explanation for why ear prints are left is straightforward; when a burglar is about to break into a home, they press their ear against the door to make sure no one is there and leave their mark. The degree of skin greasiness, whether the face or hair was applied to the same spot, or even the volume of sound they were trying to hear, can condition the fragmentations, markings and distinct patterns present on the prints. Also, during a fight or struggle, if one person presses the face of the opponent on the wall, an ear print can be formed[6].

On a crime scene, ear prints can be found on windows, doors, or windowpanes of a car, etc.

Factors which affect ear print pattern are as follows:

- A whole or fragmented impression could result from the pressure used when contacting the surface.
- The length of time spent listening, smudging from the ear moving across the surface, is more likely the longer he or she listens. This can cause the print to become obscure, making recognition a challenge.
- The quality of the listening surface, compared to uneven surfaces, smooth surfaces give a better impression.
- Print may also be influenced by the temperature, since high temperatures cause the ear's natural oil to be secreted.
- If the individual has any abnormalities in their ear.
- Ear piercings and an abundance of earrings may also affect how the pattern develops.
- A fingerprint, palm print, or other secondary print superimposed on top of another print may cause some degree of print degradation.
- Weathering may also occur between the event and the discovery of the print.
- The lifting procedure might destroy or disturb the ear print if appropriate techniques are not applied to lift it.

Collection of Ear Print

The basic process for gathering ear prints is the same as that for gathering fingerprints. It visualises prints using either;

- Physical (powder method using different coloured powders, etc.)
- Chemical methods (cyanoacrylate fuming method, ninhydrin method, iodine fuming method etc.)
- Other techniques include capturing a thermogram image of the ear, putting the ears on a flat glass to collect standards, and snapping photos.
- For casting of ear prints, dental detax resins, procedures involve using resin that solidifies after a cotton plug is inserted to create three-dimensional ear characteristics, can be used to obtain samples from an individual.

Different lifting methods include silicone-based gelatin lifters, adhesive tapes, latex or rubber lifters, etc[7].

Analysis of Ear Prints

Once the development and lifting of the print is accomplished, it is followed by analysis and comparison of the print with different known samples.

Analysis is done on the principle of individualising and matching the unknown sample with known sample.

Three general techniques have historically been employed for print comparison

- Dissection, which involves splitting the print into sections and switching them to check for coincidences and superpositions.
- The known sample and suspected sample are compared consecutively.
- Superposition, which involves superimposing one print over another with transparencies and comparing them.

Ear print identification is done in several steps, including group identification exams, contour method, methods of common traits, and assessment of supporting and contrasting evidence. Numerous factors can influence how closely an ear print resembles the genuine ear. Depending on the amount of pressure applied, both the size and the distances between the various points of reference can change. The print collecting and analysis techniques are intended to try to address these issues[8].

Maat suggested a quantitative categorisation approach based on a polar axis that is developed or drawn using a vertical line that is the tangent shared by the tip of the tragus and the internal margin of the imprint of the antero-superior curve of the helix. For this reason, Ingleby uses a computer to compute it using "centroids" (centres of intensity).

Digital techniques are being developed for the ear print analysis, one such technique is "Forensic Identification (FearID)". It is a study project developed to check the credibility of the ear print found at the crime scene. This study is being conducted in the European Union. Additionally, it is working on creating an international database of ear prints.

The analysis of the length and breadth of the ear can be used for evaluation. Some scholars, however, because they have characteristics in common with the majority of people, these characteristics are referred to as class characteristics rather than individual characteristics. Some studies believe that physical deformities from accidents or diseases, birthmarks, scars, etc., can be used to determine an individual's level of uniqueness[9].

Significance of Ear Print in Forensic Science

- According to reports, with some adjustments, the ear print can be used to estimate the suspect's height based on the floor-to-print distance.
- It can be useful for determining the presence of a person at the crime scene.
- Identifying an individual from ear print can be a challenging task.
- It is possible to identify a mobile phone user by their ear print.
- It has also been concluded in some studies that face recreation can be possible if size and form ear is known.
- Additionally, it can be utilised to compare with the database in cases where there are no suspects[10].

Validity of Ear Print in Court as Evidence

The ability to identify a specific ear print as belonging to a specific subject is the foundation of the forensic validity of the print. This can be used to exclude a subject as a suspect, strengthen the evidence against a certain suspect, or even look for suspects in databases in the future if none exist.

Its widespread use in the community or in other courts, articles and publications, and the testimony of those who affirm it are all examples of general acceptance. There cannot be widespread acceptance if there is significant dispute among informed experts about the validity of the scientific evidence. It can only act as a piece of corroborative evidence which supports other evidence.

Ear prints are becoming more and more acknowledged as a possible forensic identifying tool, although their legality as a stand-alone identification technique is still up for question. These problems are made worse by the subjectivity of the analysis, the lack of defined protocols, and the possibility of print variability brought on by pressure and other variables[11].

Limitations of Ear Print

- There are issues with reproducibility and dependability because ear print analysis is primarily subjective, and lacks established scientific procedures.
- Since a single ear can create several prints depending on the angle, pressure, and surface texture, direct comparison is challenging.
- Ear print analysis is frequently utilised in conjunction with other forms of evidence, such DNA or other biometric data, rather than by itself for identification.
- The broad adoption of ear prints as a trustworthy forensic identification technique is not supported by thorough and consistent scientific study.
- It is typically positioned in easily accessible public spaces that can be significantly disrupted by the presence of other prints.
- The inability to ascertain the imprinting time could lead to innocent people being mistaken at the scene of the crime.
- Whether two different ears could leave the same or a similar print is another question, or if there is enough inter-individual variability to be able to tell two distinct ears apart in any circumstance.
- A print in the database may eventually lose its ability to be recognised as a legitimate match for a variety of reasons over a period.
- It is also essential to note that as years pass, the morphology of the ear of a person changes, which will ultimately result in an inability to identify the individual[12].

Advances in Ear Print Analysis

- Biometric ear print has distinct personal traits that can be utilised for identification, much like fingerprints.
- It is possible to identify suspects or rule them out of the inquiry by comparing databases of known ear prints with latent ear prints, which are imprints left on surfaces.
- Research projects like the EU-funded Forensic Ear Identification (FearID) project are building extensive databases for ear print analysis.
- To increase the precision and effectiveness of ear print analysis, methods such as thermal image analysis and real-time picture analysis from CCTV are being employed.
- According to studies, male and female ear morphology might differ, which could help with sex identification in forensic situations.
- In cases of mass disasters or when remains are seriously injured, ear prints can be used to identify people.
- To improve identification even more, researchers are looking at the possibility of removing DNA from ear prints.
- The process of comparing ear prints is being automated using techniques like those created in the FearID project, which increases accuracy and efficiency[13].

Conclusion

Compared to other methods like fingerprints and DNA, ear print evidence is still regarded as a relatively recent identification technique. Its potential seems not fully realised yet. Its scope is likewise constrained because it appears that the problem is only addressed in a small number of circumstances. The main question is whether ear print evidence is a valid and trustworthy means of identification.

To improve the precision and dependability of ear print evidence, more study in this field is required, as well as an adaptation of existing methods. If this were possible, ear print evidence would be readily admitted by the courts and might be a potent instrument for convicting criminals.

Ear print analysis has emerged as a useful forensic method for suspect identification, especially in investigations into violent crimes and burglaries. There are still issues with its admissibility and

dependability despite its benefits, which include resistance to forgery and distinctive biometric features.

To improve the legitimacy and acceptability of ear print evidence in court going ahead, additional research, standardised processes, and expert training are necessary. In the event that these advancements occur, forensic investigations may find ear print analysis to be a useful adjunct tool that facilitates the pursuit of justice.

Source of Funding: This work did not receive any specific grant from funding agencies in the public, commercial or non-profit sectors.

Conflict of Interest: The author declares no conflict of interest related to the content or authorship of this manuscript.

Ethical Considerations: This article is based solely on previously published research papers and extensive literature review. It does not involve any studies with human or animal subjects performed by the authors. Hence, ethical approval was not required.

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Original Article DOI: https://doi.org/10.37506/0wm12x39

Molecular Forensics of Indian Wildlife: Species Identification through COI Gene Barcoding and Bioinformatics Analysis

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How to cite this article: Khushi Jain, Rakesh Mia. Molecular Forensics of Indian Wildlife: Species Identification through COI Gene Barcoding and Bioinformatics Analysis. Medico-Legal Update / Vol 25 No. 4, October - December 2025

Abstract

In wildlife forensics, precise species identification is essential, particularly in cases involving poaching, illegal wildlife trade, and biodiversity conservation. Molecular technologies are necessary for accurate forensic analysis since traditional morphological methods frequently fail when biological specimens are processed, incomplete, or degraded. Mitochondrial DNA (mtDNA) has proven particularly useful in these situations because of its large copy number, maternal mode of inheritance, and increased stability in damaged tissues. The cytochrome c oxidase subunit I (COI) gene is one of the most commonly used mtDNA markers for DNA barcoding due to its high interspecies variability, evolutionary conservation, and inclusion in extensive international databases.

This study examined the COI gene sequences of ten often encountered domestic and wild Indian species: *Elephas maximus* (elephant), *Bos gaurus* (gaur), *Bos taurus* (domestic cow), *Axis axis* (chital), *Axis porcinus* (hog deer), *Macaca mulatta* (rhesus macaque), *Pavo cristatus* (Indian peacock), *Sus scrofa* (wild boar), and *Panthera tigris* (tiger) and *Panthera pardus* (leopard). COI sequences that are publicly accessible were obtained from NCBI GenBank database. BLAST was used for sequence validation, and Clustal Omega was used for multiple sequence alignment. Using MEGA12, a neighbor-joining tree was constructed and pairwise distance analysis was performed to evaluate genetic distance and phylogenetic relationships.

Significant genetic divergence was found among the species under study, and the phylogenetic tree showed grouping patterns that aligned with established taxonomic relationships. These results demonstrate that COI-based DNA barcoding is a reliable method for differentiating between closely related species.

Keywords: species identification, cytochrome c oxidase subunit I (COI gene), mitochondrial DNA (mtDNA), DNA barcoding, wildlife forensics, bioinformatics tools

Introduction

Identification of species is essential to ecological monitoring, forensic science, and biodiversity protection.[1] When it comes to wildlife forensics, precise species identification is essential for preventing illicit poaching; stopping wildlife trafficking, and upholding laws protecting wildlife.[2]It is necessary for both legal processes and the preservation of endangered animals. The significance of accurately identifying species cannot be emphasized in a biodiverse nation like India, which is home to numerous endangered species.

Species identification in wildlife forensics has always depended on the morphological and anatomical analysis of physical remains. Bones, feathers or hair, teeth, eggshells, claws or paws, and

Submission: Jul 22, 2025 **Revision:** September 5, 2025 **Published date: September 25,2025**

ivory are examples of common biological materials.[3] Even while these traditional methods have proven useful, they frequently have drawbacks when samples are degraded, damaged, or lack identifiable morphological characteristics.[4] Consequently, molecular methods like DNA barcoding with mitochondrial genes have become more accurate, repeatable, and dependable methods for identifying species, particularly in wildlife forensic investigations.[5]

A number of characteristics, including its high copy number per cell, lack of recombination, rigid maternal inheritance, heteroplasmy, fluctuating gene expression, and mitotic segregation, make mitochondrial DNA (mtDNA), an extra-nuclear genome, particularly useful in forensic investigations.[6]

The Cytochrome c oxidase subunit I (COI) gene has emerged as the most reliable marker for DNA barcoding among a variety of mitochondrial markers.[7] With the help of a comprehensive worldwide reference database that includes resources like GenBank and the Barcode of Life Data System (BOLD), the COI gene allows for precise identification between closely related species.[8] However, due to a lack of standardized procedures in forensic casework and a lack of reference data for specific species, precise mtDNA species identification remains difficult in India.[9]This study aims to evaluate how well the COI gene identifies animal species in Indian forensic cases with bioinformatics tools for phylogenetic analysis and sequence alignment.

By examining the COI gene sequences of ten Indian species that are commonly found in wildlife crime cases, our study seeks to close these gaps. These species are: *Panthera tigris* (tiger), *Panthera pardus* (leopard), *Elephas maximus* (elephant), *Bos gaurus* (gaur), *Bos taurus* (domestic cow), *Axis axis* (chital), *Axis porcinus* (hog deer), *Macaca mulatta* (rhesus macaque), *Pavo cristatus* (Indian peacock), and *Sus scrofa* (wild boar).These species were chosen to reflect a wider taxonomic range as well as closely related species pairings (such as tiger vs. leopard, gaur vs. cow, and chital vs. hog deer), in addition to their ecological significance and legal protection under India's Wildlife (Protection) Act. A thorough assessment of the COI gene's discriminating ability across various species relatedness levels was made possible by this selection.

The following steps are frequently included in the standard workflow for molecular species identification: (1) DNA isolation from the biological sample; (2) quantification of the extracted DNA; (3) PCR amplification of a specific region of mitochondrial DNA (mtDNA); (4) gel electrophoresis verification of successful amplification; (5) purification of the PCR amplicon; (6) bidirectional sequencing of the purified product; and (7) comparison of the obtained sequence data with reference databases like GenBank or ForCyt.[10]Although species identification also uses additional mitochondrial genes including cytochrome b, 12S rRNA, and 16S rRNA, the COI gene is still the most used and accepted marker for DNA barcoding.

In order to investigate evolutionary links, this study will extract COI sequences from NCBI GenBank[11],validate them using BLAST[12], align them using Clustal Omega[13], and perform pairwise distance analysis and phylogenetic analysis using MEGA12 software[14]. The research's findings are intended to support forensic investigations, create a unified reference for Indian species, and advance the creation of standardized procedures in wildlife forensics. This study emphasizes how crucial molecular-based species identification is to both improving forensic techniques in wildlife crime investigations and conserving India's biodiversity.[15]

Materials and Methods

The present study employed an in-silico methodology to show that, instead of depending on traditional wet-laboratory techniques, species identification and COI gene analysis may be successfully performed using open-access databases and bioinformatics tools[16]. The objective was to demonstrate the reflecting both the potential and existing challenges of applying computational methods in wildlife forensic investigations by offering a non-invasive, cost-effective, and time-efficient substitute for species identification and

biodiversity analysis[17]. The full study was carried out in April 2025 over a period of one month.7)

Ten species of great forensic and conservation significance in the Indian context were selected based on their frequent use in genetic studies and documented relevance in forensic casework[18, 19]. These are:*Panthera tigris* (tiger), *Panthera pardus* (leopard), *Elephas maximus* (elephant), *Bos gaurus* (gaur), *Bos taurus* (domestic cow), *Axis axis* (chital), *Axis porcinus* (hog deer), *Macaca mulatta* (rhesus macaque), *Pavo cristatus* (Indian peacock), and *Sus scrofa* (wild boar). In India, these species are commonly found in incidents of illicit poaching, wildlife trafficking, and conservation issues.A common and well tested marker for animal DNA barcoding, the cytochrome c oxidase I (COI) gene was deliberately targeted due to its great inter-species diversity and universality.[7]

Each species' COI gene sequences were obtained from the National Center for Biotechnology Information (NCBI) GenBank database.[11]Species-specific keywords (e.g., "Panthera tigris COI gene") were used in a concentrated search. Initial shortlisting of two to three sequences per species was done using certain criteria: high-quality annotation with few ambiguities or unidentified nucleotides; availability of voucher or isolate information; & sequence length (full-length barcodes of roughly 650 bp) [20]. After a thorough analysis, the chosen sequences were downloaded in FASTA (.fasta) format. Only dependable and representative sequences were used for subsequent studies because of this retrieval procedure.

Table 1. A list of specific wildlife species from India that have been selected for in-silico analysis, along with their common names, GenBank accession numbers, and COI gene sequence lengths (in base pairs).

S. No.	Species Name	Common Name	Accession No.	Sequence Length (bp)
1	*Panthera tigris*	Bengal Tiger	MZ099332.1, MZ099331.1	663
2	*Panthera pardus*	Leopard	MZ049429.1, MZ049428.1	658
3	*Elephas maximus*	Indian Elephant	MZ061670.1, MZ061669.1, MZ046731.1	658
4	*Bos taurus*	Domestic Cow	MN714170.1, MZ049020.1, MZ049018.1	16338,658
5	*Bos gaurus*	Gaur	KF808255.1	606
6	*Axis axis*	Chital	KT372098.1, MN226859.1	1545,567
7	*Axis porcinus*	Hog Deer	KF509980.1, KF509978.1, KF509976.1	684,691
8	*Macaca mulatta*	Rhesus Monkey	OR290636.1, OR290633.1, OR290630.1	672,675
9	*Pavo cristatus*	Indian Peacock	LC018112.1, GQ922638.1, GQ922612.1	773,699
10	*Sus scrofa*	Wild Boar	OK244645.1, MT251432.1, KY661881.1	1545,657,697

The Basic Local Alignment Search Tool[12]for nucleotides (BLASTn tool) was used to confirm the species identity upon collection by comparing it to the NCBI nucleotide database. After uploading each FASTA sequence to BLASTn, the highest-scoring hits were assessed using the following criteria: minimum E-value, maximum score, maximum percentage identity, and query coverage. Sequences that demonstrated accurate taxonomic placement and top alignment scores were chosen for additional research. The highest-scoring accession was taken into consideration when the first downloaded sequences did not match the best BLASTn hit. By taking this step, the possibility of dealing with incomplete, poor-quality, or incorrectly recognized sequences was reduced, guaranteeing one high-confidence COI sequence for every target species.

Table 2. BLAST results for each chosen species, including the associated final GenBank accession number, top match species, sequence identity, query coverage, E-value, and maximum score.

S. No.	Species Name	Top BLAST Hit	%Identity	Query coverage	E-value	Max Score	Final Accession No.
1	*Panthera tigris*	*Panthera tigristigris*	100%	100%	0.0	1225	MZ099332.1
2	*Panthera pardus*	*Panthera pardus*	100%	100%	0.0	1216	MZ049428.1
3	*Elephas maximus*	*Elephas maximus*	100%	100%	0.0	1216	MZ061669.1
4	*Bos taurus*	*Bos taurus*	100%	100%	0.0	1216	MN714170.1
5	*Bos gaurus*	*Bos gaurus*	100%	100%	0.0	1120	KF808255.1
6	*Axis axis*	*Axis axis*	100%	100%	0.0	2845	KT372098.1
7	*Axis porcinus*	*Axis porcinus*	100%	100%	0.0	1277	KF509976.1
8	*Macaca mulatta*	*Macaca mulatta*	100%	100%	0.0	1206	OR290633.1
9	*Pavo cristatus*	*Pavo cristatus*	100%	100%	0.0	1291	LC018112.1
10	*Sus scrofa*	*Sus scrofa cristatus*	100%	100%	0.0	1214	OK244645.1

To ensure correct format compatibility with Clustal Omega, the separate FASTA files were combined using Command Prompt operations prior to executing alignments. In addition to a single combined FASTA file with the sequences of all 10 species, separate combined files were created for closely related species pairings (*Panthera tigris* vs. *Panthera pardus*, *Bos gaurus* vs *Bos taurus*, and *Axis axis* vs *Axis porcinus*).

Clustal Omega[13], an online program designed to handle big and complicated biological datasets, was utilized to perform multiple sequence alignment. Guide trees and hidden Markov models are used in the tool's scalable and quick progressive alignment process, which guarantees accuracy and speed. The output was produced in ClustalW format, and the alignment was carried out with the default parameters. Although manual reformatting was necessary to ensure compatibility with MEGA12, Clustal Omega's accuracy in preserving the biological integrity of the sequences was essential for further genetic investigation.

Pairwise distance analysis was carried out using MEGA12[14] for the fine-scale resolution of closely related species pairs. The p-distance model was adopted for the analysis because it is a popular and easy way to calculate genetic distance, and it works best for closely related species with little sequence divergence[21]. Assuming uniform substitution rates, the computation was performed using pairwise deletion of gaps and missing data.*Panthera tigris* vs. *Panthera pardus*, *Axis axis* vs. *Axis porcinus* and *Bos gaurus* vs. *Bos taurus* were the species pairs that were examined. The distance matrices that were produced supported species-level identification in wildlife forensic applications by quantifying the genetic divergence between each pair of species.

Phylogenetic trees were then built using MEGA12 using the aligned datasets. After making the required formatting changes, each file was imported into the program. The Kimura 2-parameter (K2P) model[22], a common model for DNA barcoding research that assumes uniform substitution rates across sites, was used along with the Neighbor-Joining (NJ) method to infer phylogenetic relationships. Particularly, the K2P model was selected over complex ones due to its ability to differentiate between transition and transversion rates, offering a well-balanced method that increases species-level phylogenetic analysis accuracy while preserving computing efficiency. Using a bootstrap approach with 1000 repeats, the branching patterns' reliability was evaluated. The constructed phylogenetic tree gave a visual depiction of the genetic divergences of the chosen species and showed the general evolutionary links between them.

Result and Interpretation

The NCBI GenBank[11] database was used to obtain the cytochrome c oxidase I (COI) gene sequences for the ten chosen species. These sequences were examined using the Basic Local Alignment Search Tool[12](BLASTn) to confirm species identity. With the query value and percentage identity being 100% and the E-value for each sequence being 0.0, the BLAST findings showed that the sequences were extremely accurate and specific to their respective species. These outcomes demonstrated that the sequences that were recovered were genuine and suitable for additional examination.

Sequences that did not exhibit 100% identity or had unclear findings were eliminated in order to guarantee high-quality data. This rigorous quality control procedure made sure that only sequences with high confidence were kept for further examination.

Based on the COI gene sequences of the chosen species, multiple sequence alignments were carried out using Clustal Omega[13] to evaluate the genetic differences between them. The alignment showed a mix of variable areas, which are responsible for interspecies genetic differentiation, and conserved sections, which are crucial for mitochondrial function. The alignment demonstrated the efficiency of the COI gene in species classification[7] by showing that closely related species, such those in the Panthera genus, had significant sequence similarity while more distantly related species showed more divergence. The p-distance model of MEGA12[14] was used to create genetic distance matrices that measured the genetic divergence between species pairings. For the chosen species pairs, the p-distance values were as follows:

Table 3. Genetic distance (p-distance) calculations based on COI gene sequences between pairs of closely related species.

Species 1	Species 2	Genetic Distance (p-distance)
Panthera tigris	*Panthera pardus*	0.0714
Bos taurus	*Bos gaurus*	0.0693
Axis axis	*Axis porcinus*	0.706

Closely related species, like *Bos taurus* vs. *Bos gaurus* and *Panthera tigris* vs. *Panthera pardus*, had relatively low p-distance values because of close genetic relationships. Nonetheless, **there appears to be significant genetic diversity between *Axis axis* (chital) and *Axis porcinus* (hog deer), as indicated by the noticeably high p-distance between these two species. This discovery calls for more research since it suggests either an unexpectedly high evolutionary distance[23] within the Axis genus or possible problems with sequence quality[24].**

The aligned COI gene sequences and the Kimura 2-Parameter[22] (K2P) model with 1000 bootstrap replicates in MEGA12 were used to create a Neighbor-Joining phylogenetic tree. The species were clearly divided into several clades by the tree, which matched their taxonomic identities.

While more distantly related species, like *Bos gaurus* and *Bos taurus*, appeared in separate clades, closely related species, such *Panthera tigris* and *Panthera pardus*, were placed close to one another on the tree. Significantly, **species pairs such as *Axis axis* and *Axis porcinus* were positioned on different branches, which is in accordance with the p-distance analysis's finding of substantial genetic divergence.** The ability of COI sequences to differentiate species

across different taxonomic groups was further supported by the formation of individual, well-supported clades with high bootstrap values[25] by other species, such as *Elephas maximus* (elephant), *Sus scrofa* (wild boar), *Macaca mulatta* (rhesus macaque), and *Pavo cristatus* (Indian peacock).

The research validated the usefulness of this gene marker for forensic applications[26] in animal species identification by showing that COI gene sequences may successfully distinguish between closely related and distantly related species.

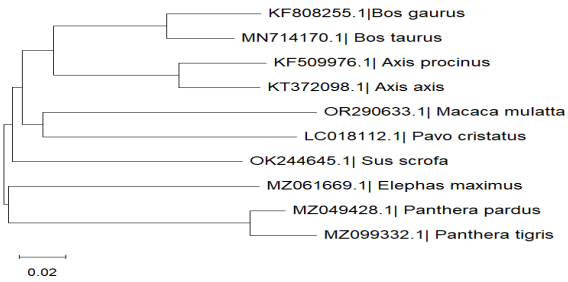

Figure 1: A neighbor-joining phylogenetic tree based on the Kimura 2-Parameter (K2P) model with 1000 bootstrap repetitions in MEGA12 was built utilizing COI gene sequences from ten Indian wildlife species.

Discussion

The efficiency of mitochondrial COI gene sequences in differentiating closely and distantly related Indian wildlife species is confirmed by this in-silico investigation. For all ten taxa, BLAST analysis yielded initial high-confidence species-level identification with 100% query coverage and identity and 0.0 E-values.[11,12] Although BLAST is sufficient for high-quality samples, the limitations in cases of degradation or ambiguity underscore the necessity of additional techniques.[2]

According to Sievers et al., the use of Clustal Omega[13] for multiple sequence alignment increased alignment accuracy, especially when distinguishing closely related species such as *Panthera tigris* and *Panthera pardus*. Additionally, alignment made it possible to detect minute nucleotide variations, which are essential in forensic situations involving deteriorated samples.

Species-level variations were confirmed by genetic distance analysis (p-distance model) of MEGA12[14]. Clear separation was nevertheless possible despite limited divergence between species pairs, such as *Bos gaurus* and *Bos taurus* (0.0693) and *Panthera tigris* and *Panthera pardus* (0.0714). *Axis axis* and *Axis porcinus* have a very high divergence (0.706), which could indicate either major evolutionary separation or inconsistent data. In situations where BLAST is inconclusive, genetic distance analysis bolster forensic evidence.

Strong bootstrap values supported the Neighbor-Joining phylogenetic tree, which was built using the Kimura 2-Parameter[22] model. It clustered species based on their taxonomy and revealed separate clades even among genetically identical species[27]. Phylogenetic trees offer important evolutionary insights, even if they are not always necessary in forensics, particularly in court cases involving endangered species.

The current work expands and improves on earlier studies on the use of DNA barcoding for wildlife identification. The use of the COI gene for species-level identification was first introduced by Hebert et al., although their research was more widely distributed and did not really address the forensic context of Indian wildlife[7]. Ogden et al. established BLAST's usefulness in wildlife forensics, but also acknowledged its limitations for degraded materials[2]. To improve the accuracy of species identification, the current study uses a multi-layered strategy that includes BLAST, multiple sequence alignment, genetic distance analysis, and phylogenetic reconstruction. Verma and Singh looked at the phylogenetics of Indian mammals; however they lacked rigorous sequencing validation and fine-scale resolution[27].

Our work uses strict quality control, choosing only sequences with 100% identity and 0.0 E-values. It also identifies exceptional divergence within the Axis genus, which may indicate a need for additional taxonomic clarification or considerable evolutionary separation. As a result, the study provides methodologically sound, forensically relevant, and region-specific findings that enhance previous methodologies.

The present study has certain limitations. The analysis was based on a limited number of species samples, which may not fully capture the genetic diversity of all possible organisms. Further, the study relied only on the COI gene for species identification, whereas the inclusion of additional markers could improve accuracy and resolution. Another limitation is the dependence on online databases such as BLAST, where the availability and completeness of reference sequences directly affects the results. COI barcoding has limitations, including the potential inability to distinguish hybridizing or closely related species and the potential for errors due to amplifying nuclear pseudogenes (numts) [28, 29]. Additionally, because COI is a mitochondrial marker, its results must be interpreted cautiously, and alternative markers may be needed in complex cases.

However, the study can be extended by increasing the sample size and including more diverse species the findings would be more reliable and widely applicable. Incorporating multiple genetic markers, such as 16S rRNA or cyt b, alongside COI could strengthen species identification and phylogenetic analysis. Developing a local reference DNA barcode database and applying advanced bioinformatics tools or next-generation sequencing can further improve species identification and strengthen forensic applications.

Conclusion

The usefulness of mitochondrial COI gene barcoding as a potent species identification technique in Indian wildlife forensics is further supported by this in-silico study. Clear species difference across ten different taxa was accomplished by the study by using a variety of bioinformatics techniques, such as sequence verification, alignment, phylogenetic analysis, and genetic distance computations. The COI marker's ability to capture genetic distinctiveness is demonstrated by the consistency of results, especially when comparing closely related species.

Crucially, the study shows that whereas quick identification methods perform well in ideal circumstances, complicated forensic situations—like those involving deteriorated samples or closely related species—call for a more sophisticated analytical approach. Methods such as tree-based inference and multiple sequence alignment provide insightful information that enhances the validity and dependability of conclusions based on DNA.

The use of reliable molecular techniques is essential given the surge in wildlife crimes, including poaching and illegal trading. COI barcoding is becoming more and more supported by this type of research as a method of conducting forensic investigations that is both legally and scientifically sound. It is a vital tool for forensic labs and animal conservation organizations due to its affordability, versatility, and connectivity with digital databases.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

Ethical Clearance: Not required as study does not employ live subjects

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Original Article

DOI: https://doi.org/10.37506/gy6bpp92

Psychological Consequences of Whistleblower Retaliation in India's Healthcare Sector: A Forensic Qualitative Study

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How to cite this article: Ved Ashish Nanoty, Anshnu Tyagi. Psychological Consequences of Whistleblower Retaliation in India's Healthcare Sector: A Forensic Qualitative Study. Medico-Legal Update / Vol 25 No. 4, October - December 2025

Abstract

Whistleblowing in India's healthcare sector involves significant personal, professional, and psychological risk. While legal frameworks like the Whistleblower Protection Act (2014) exist, the emotional and mental health consequences of retaliation remain under-researched, particularly through forensic psychological and culturally informed lenses. This qualitative study explores the psychological impact of whistleblower retaliation among healthcare professionals across government, private, and semi-government institutions. Grounded in a constructivist paradigm, the study employed semi-structured, in-person interviews with 20 participants, including doctors, nurses, interns, administrators, and allied health workers selected through purposive and snowball sampling.

Using Braun and Clarke's (2006) thematic analysis, six key themes emerged: psychological impact, forms of retaliation, barriers to whistleblowing, institutional silence and mental health apathy, coping strategies, and reform recommendations. Participants reported symptoms such as anxiety, depression, insomnia, emotional withdrawal, and somatic distress, often shaped by cultural values of obedience, hierarchy, and shame. The study introduces two novel constructs, shame-based silencing and learned despair, to describe trauma responses stemming from institutional betrayal and social invalidation.

Findings highlight a lack of effective support systems, with grievance mechanisms seen as performative and mental health services perceived as inaccessible or biased. Forensic psychology offers a lens to reframe whistleblowers not as threats but as morally driven individuals in need of empathy, protection, and trauma-informed care. The study calls for urgent, culturally sensitive reforms in policy, training, and mental health infrastructure, positioning psychological well-being as essential to ethical governance in healthcare.

Keywords: Whistleblower Retaliation, Forensic Psychology, Indian Healthcare, Psychological Trauma, Moral Injury, Institutional Silence

Introduction

Globally, whistleblowers are seen as defenders of integrity, yet in rigid institutions like healthcare, speaking out often brings emotional trauma, mental health decline, and identity erosion[1].While international studies document these harms, forensic psychological perspectives in non-Western contexts remain scarce.

In India, whistleblowing disrupts deeply rooted cultural norms of hierarchy, silence, and obedience (BMJ, 2015). Healthcare professionals who expose wrongdoing whether procedural violations, patient neglect, or corruption, risk retaliation beyond job loss,

Submission: Jul 5, 2025 **Revision:** September 11, 2025 **Published date: September 25, 2025**

enduring social isolation, character assassination, and systemic erasure. The Whistleblower Protection Act (2014) exists, but it offers little real psychological or institutional support[2].

Despite extensive policy analyses, few studies examine the mental health fallout, especially in healthcare, or how gender, hierarchy, and cultural conditioning shape these experiences[2]. This study fills that gap, giving voice to silenced whistleblowers through a culturally informed forensic psychological lens.

Statement of the Problem

Despite legal protections, whistleblowers in India's healthcare sector face systemic retaliation, ranging from workplace exclusion and legal threats to humiliation and mental health decline. Existing research overlooks the psychological impact of such retaliation, especially through a trauma-informed forensic lens. Additionally, the gendered nature of these experiences remains underexplored. This study addresses these gaps, aiming to uncover what institutions deny and individuals are forced to suppress.

Purpose of the Study

This study explores the psychological impact of whistleblower retaliation in India's healthcare sector through semi-structured interviews with affected professionals. It examines emotional distress, trauma responses, coping strategies, and the influence of gender and institutional hierarchy. Using a forensic psychological lens, the research aims to validate lived experiences and inform recommendations for mental health support and systemic reform.

Significance of the Study

This research is more than just a study; it is a step toward justice and support. It helps mental health professionals, especially those working with workplace stress and trauma, understand the deep emotional impact faced by whistleblowers. It also gives useful ideas to policymakers and hospital leaders who want to make healthcare systems more honest and fairer. In India, the trauma of whistleblowers has not been studied enough, and this research helps fill that gap. By sharing the emotional struggles of those who speak up, the study shows that whistleblowers are not troublemakers, but brave individuals who deserve care, respect, and protection. It also helps guide changes that are sensitive to trauma, gender, and culture.

Theoretical Framework

This forensic psychology study draws on Trauma Theory to show how whistleblower retaliation causes emotional wounds through betrayal, helplessness, and chronic stress. Organizational Justice Theory explains how institutional unfairness deepens this pain[3,4]. A social constructionist lens reveals how Indian cultural norms of silence, authority, and shame shape responses to whistleblowers. The trauma arises not from isolated incidents but from systemic, cultural punishment of honesty and dissent.

Research Method

A qualitative design was chosen for its ability to capture emotional nuance and complexity. Using survey-based, semi-structured interviews, this study collected in-depth narratives from whistleblowers within the Indian healthcare system. The interviews featured open-ended questions designed to elicit emotional, psychological, and experiential data. This approach aligns with Creswell (2014) and Merriam (2009), who emphasize the value of narrative inquiry in exploring hidden or stigmatized phenomena. Thematic analysis was then used to identify recurring patterns, with a focus on emotional content, trauma indicators, and systemic behaviors[4,5].

Definition of Key Terms

- Whistleblower: An individual who exposes illegal, unethical, or unsafe practices within an organization[6].
- Retaliation: Any punitive action taken in response to whistleblowing, including harassment, professional exclusion, or psychological harm[7].

- Moral Injury: Emotional distress resulting from actions that violate one's moral or ethical code[7].
- Forensic Psychology: A field at the intersection of psychology and the justice system, concerned with the psychological aspects of legal and institutional processes[8].
- Whistleblower Protection Act (2014): Indian legislation designed to protect individuals who report corruption or misconduct, though criticized for weak implementation.

Limitations

- Small sample size (n = 20) limits the generalizability of findings.
- Purposive and snowball sampling may have introduced bias, as only emotionally ready or well-connected individuals participated.
- Limited geographic and institutional diversity; rural and marginalized voices were underrepresented.
- Most interviews were not audio-recorded due to ethical concerns, possibly reducing emotional and nonverbal depth.
- Translation from Hindi may have led to a loss of nuanced meanings.
- Gender differences and role-based comparisons were not deeply explored.
- Findings may not apply to other sectors or broader cultural contexts.

Research Methodology

This chapter outlines the philosophical and methodological foundation of the current study, which investigates the psychological impact of retaliation on whistleblowers within India's healthcare sector. Rooted in a constructivist paradigm, the study adopts a qualitative designto gain a nuanced understanding of individual lived experiences, trauma, and copingmechanisms through the lens of forensic psychology.

Research Design

The study follows a qualitative, descriptive research design, utilizing structured, in-person interviews. A printed questionnaire was used to guide the conversations, facilitating deep reflection and emotional openness. This offline format ensured richer narrative data compared to traditional online or real-time interviews, while maintaining confidentiality and rapport.

Research Questions

The following questions guided the study:

- RQ1: How do whistleblowers in the Indian healthcare sector describe their experiences of retaliation?
- RQ2: What emotional and psychological consequences do they face?
- RQ3: What coping strategies are adopted to deal with retaliation-induced trauma?
- RQ4: How are institutional and external support systems perceived by whistleblowers?

Setting and Participants

Data was collected over four weeks in Mumbai and Delhi through structured interviews. Locations included quiet staff lounges, academic spaces, and hospital offices to ensure privacy and comfort. Participants consisted of 20 individuals, including doctors, nurses, administrators, interns, allied staff, and ward assistants from government, private, and semi-government institutions.

Sampling Method

A combination of purposive and snowball sampling was employed. Initial participants were selected based on direct whistleblowing experiences, followed by referrals through trusted networks. This approach enabled access to a vulnerable and often hidden population. Eligibility was confirmed in person, and informed consent was obtained before participation.

Data Collection Instrument

A printed, structured questionnaire with 20 questions across six thematic sections was used. It included both open-ended and categorical items, focusing on:

- Whistleblowing incidents
- Retaliation experiences
- Psychological impact
- Institutional support
- Coping mechanisms
- Reform suggestions

Responses were documented manually unless participants consented to audio recording. Interviews were conducted in Hindi or English, with translation and cultural sensitivity applied during transcription.

Data Analysis

The data was analyzed using Braun and Clarke's (2006) Thematic Analysis, involving familiarization with the responses, manual coding of both handwritten and digitized notes, and clustering of codes into broader themes such as emotional impact, institutional gaps, and barriers to whistleblowing[8]. Representative quotes were selected to support key findings, and final themes were cross-validated with existing literature. The analysis followed an inductive approach, allowing themes to emerge organically from participants' narratives.

Ethical Considerations

Given the emotional sensitivity of the topic, the study upheld high ethical standards:

- Voluntary participation and right to withdraw
- Anonymity maintained, no identifiers recorded
- Interviews held in emotionally safe environments
- A handout with mental health resources was shared
- All data is securely stored and accessible only to the research team

Limitations

The study is limited by its relatively small sample size, which restricts the generalizability of findings to the wider healthcare population. Additionally, the use of manual coding may introduce subjective interpretation and researcher bias, despite efforts toward reflexivity and audit trails. Lastly, the emotionally sensitive nature of the topic may have led some participants to withhold details, even with assurances of confidentiality and anonymity.

Findings

This chapter presents findings from a qualitative study on the psychological impact of whistleblower retaliation in Indian healthcare. Based on interviews with 20 professional doctors, nurses, administrators, and allied staff from government, private, and semi-government institutions, it identifies key themes drawn from their lived experiences.

Participants

The study included 20 participants: doctors, nurses, admins, interns, allied staff, and ward assistants from government, private, and semi-government institutions, with experience ranging from trainee to 20+ years. Purposive sampling ensured diversity. Identities were anonymized. Thematic analysis revealed six core themes: psychological impact, retaliation, barriers, institutional apathy, coping, and reform, highlighting both commonalities and role-based differences.

Data Analysis and Coding

Theme 1: Psychological Impact of Retaliation

Many participants reported lasting psychological distress, anxiety, shame, panic attacks, and depression following whistleblowing. These symptoms were chronic, compounded over time, and closely tied to professional alienation[9,10,11]. These patterns are reflected in Figure 2, which summarizes the psychological symptoms most commonly reported by whistleblowers in this study.

The lack of acknowledgment from peers and superiors deepened the trauma, making whistleblowers feel invisible. For many, retaliation reshaped their professional identity, with emotional impacts reinforcing each other over time[12].

Additionally, the relational, collective definition of self in Indian society intensifies the emotional blow: standing against authority is seen as being "rebellious, disobedient, or disrespectful," which compounds shame and isolation[13].

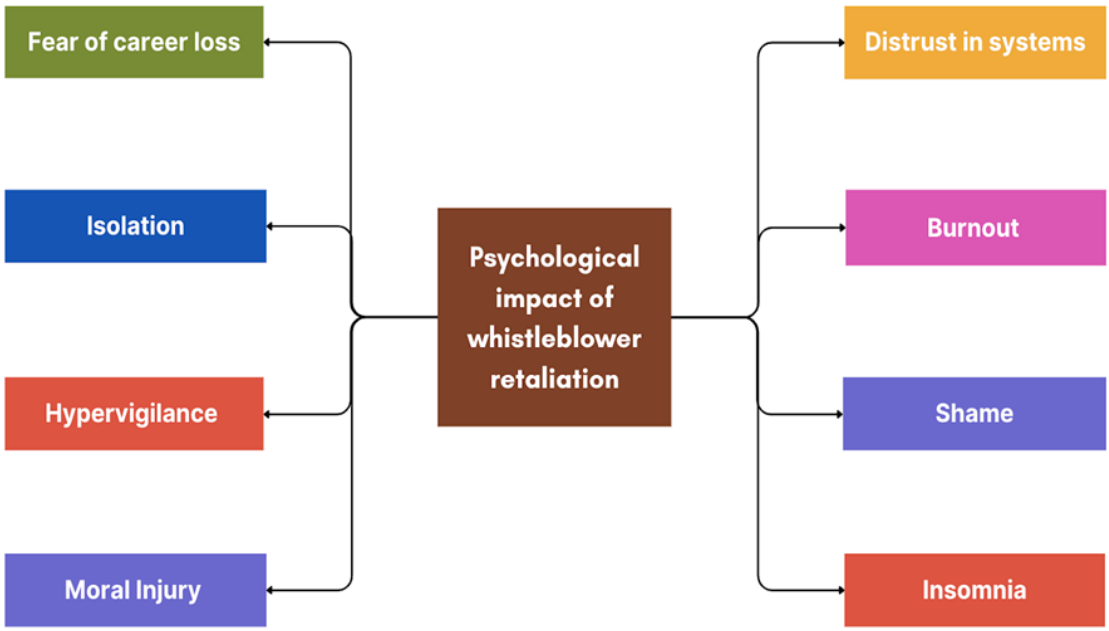

Figure 1: Emotional and Cognitive Repercussions of Whistleblower Retaliation

This mind map illustrates the core psychological outcomes experienced by healthcare whistleblowers in the aftermath of retaliation, including fear of career loss, shame, burnout, and erosion of trust in systems[14,15,16].

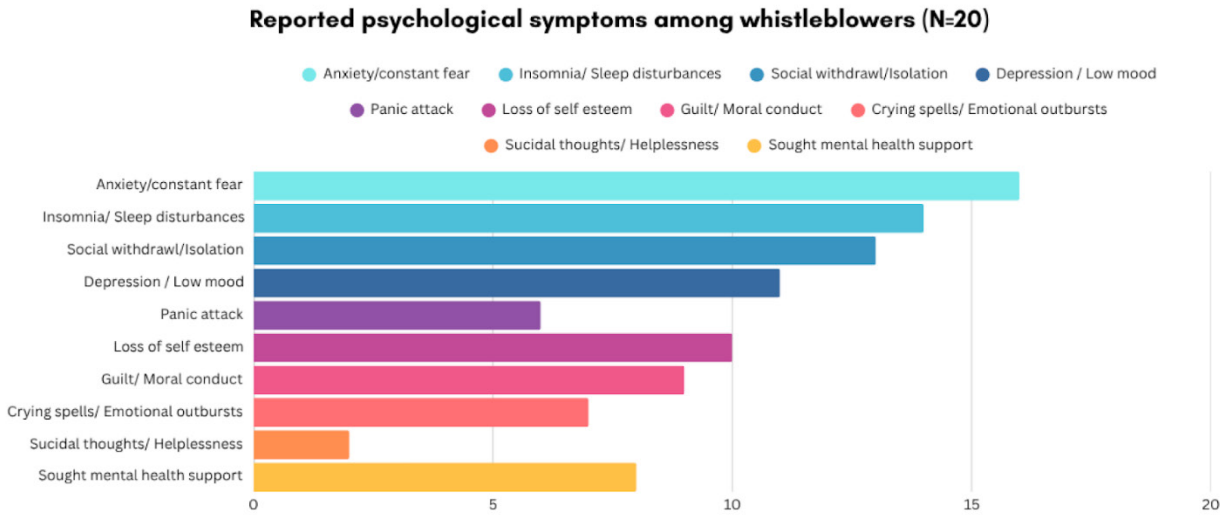

Figure 2: Reported Psychological Symptoms Among Whistleblowers (N = 20)

This chart illustrates the psychological toll of whistleblower retaliation in Indian healthcare, with anxiety, insomnia, and social withdrawal as the most reported symptoms. Only a few sought mental health supports, highlighting institutional neglect.

Source: Primary data (2025); adapted from Bjørkelo, 2013[4]

Theme 2: Forms of Retaliation Experienced

Common forms of retaliation included verbal harassment, exclusion, denied opportunities, forced transfers, and being labeled mentally unstable. Often disguised as routine administrative actions, these tactics aimed to punish dissent and deter[17]. As Figure 3 shows, such experiences spanned all roles, cutting across institutional hierarchies.

These experiences were most common in government institutions, where 60% of participants worked (Figure 4). Rigid hierarchies often normalized retaliation as institutional discipline [18,19]. Participants frequently reported anxiety, sleep issues, and social withdrawal (Figure 5). The impact was harsher for female staff and nurses, who faced both gendered and hierarchical pressures[20,21]. In India's high power-distance culture, retaliation is often framed as an administrative necessity, making it seem routine rather than punitive[22].

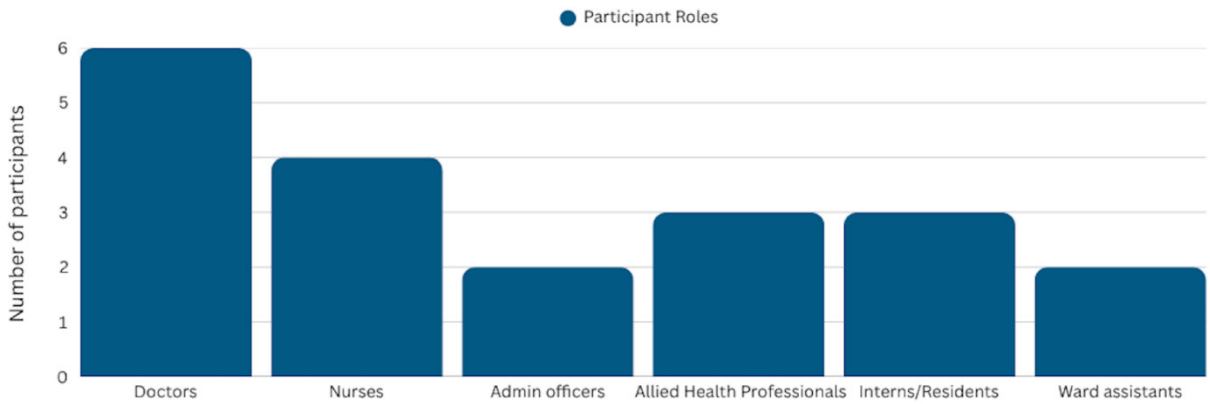

Figure 3: Occupational Roles of Participants in the Study (N = 20)

The chart displays the distribution of participant roles, highlighting diverse representation across professional hierarchies, including doctors, nurses, administrative staff, and support workers groups commonly affected by workplace retaliation[23,24].

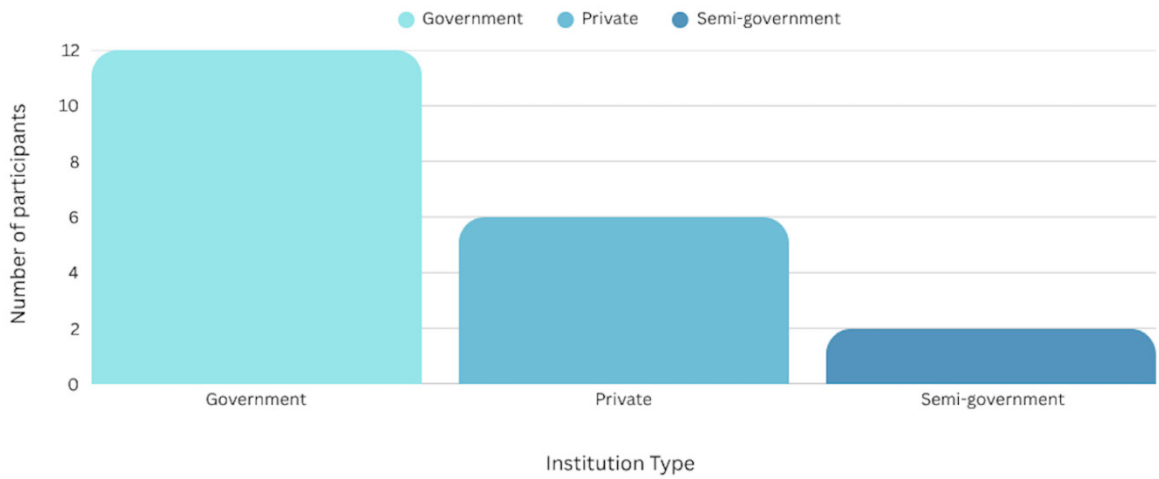

Figure 4: Distribution of Participants based on Institutions (N = 20)

Most participants were from government institutions, where entrenched hierarchies and bureaucracy often normalize retaliation as an administrative routine[25].

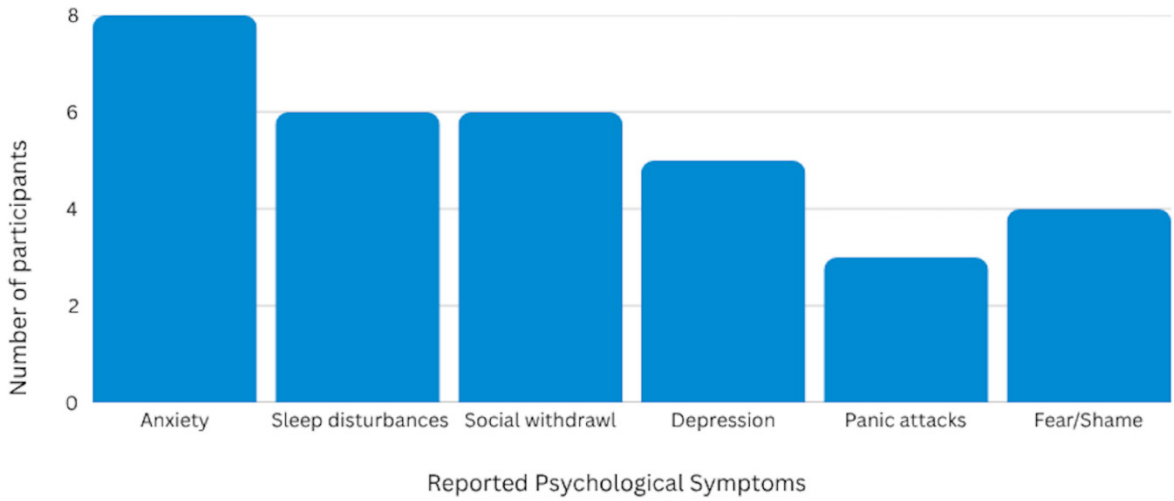

Figure 5: Distribution of Participants by Type of Psychological Symptoms (N = 20)

Anxiety, sleep issues, and social withdrawal were the most common effects, reflecting global patterns of workplace retaliation and highlighting the emotional cost of whistleblowing in hierarchical settings[26,27].

Theme 3: Barriers to Whistleblowing

Participants expressed concerns about hierarchy, career risk, and the lack of safe reporting channels. This fear was not only structural but also internalized, reflecting a culture in which questioning authority was equated with professional suicide[28,29].

Whistleblowing, even when morally justified, was often perceived as disloyalty. Participants repeatedly noted that ethical clarity rarely translated into institutional safety[30,31].

Theme 4: Institutional Silence and Mental Health Apathy

Institutions often lacked formal whistleblower protection policies or neutral mental health support [32, 33].

In the absence of institutional support, many respondents turned inward or outward to find ways to survive. Their coping mechanisms reveal resilience, but also an urgent call for reform. Indian organizational culture, influenced by collectivist and hierarchy-reinforcing values, frames whistleblowing as a betrayal against one's superior, family, or institution. Proverbs like "elders are never wrong" and "sir/ma'am culture" discourage questioning authority, even if wrongdoing is clear[34,35].

Theme 5: Coping and Survival Strategies

Respondents reported coping through silence, job shifts, therapy, and activism. These coping strategies reflected both resignation and resilience. While some withdrew, others transformed their trauma into advocacy, a silent protest that became their method of reclaiming[36,32].

In nearly all cases, these coping responses were self-initiated, without any formal guidance or institutional support. This reveals a profound gap between policy rhetoric and lived experience[40]. Many described internalizing their distress, staying silent due to cultural norms, or leaving institutions entirely, actions driven by India's shame-based culture that prioritizes reputation over individual well-being. Some individuals converted their trauma into activism, forming informal networks to advocate for change[37].

Theme 6: Recommendations for Reform

Participants emphasized the need for institutional reforms to protect whistleblowers, recommending

anonymous grievance systems managed externally, legal and ethics training, mental health helplines, and protective contract clauses. These were seen as essential for building a safer, more accountable environment[38].

As illustrated in Table 1, participant narratives not only revealed psychological distress and systemic barriers but also articulated clear recommendations for reform, emphasizing the urgent need for institutional accountability and culturally sensitive safeguards.

Participants stressed that reforms must challenge cultural norms of hierarchy and obedience. Effective protections require anonymity and neutral oversight to counter the "elders-are-never-wrong" mindset[39,27].

Table 1. Thematic Coding of Participant Narratives with Representative Quotes and Translations.

Theme	Sub-Themes / Codes	Example Quotes from Participants (With English Transcription)
1. Psychological Impact and Retaliation	Anxiety, Depression, Panic Attacks, Shame, Sleep Disturbance, Isolation	I became very anxious. I couldn't sleep at night…"I used to cry without any reason. I felt like I was the foolish one. "Sleepless nights are a big one... self-esteem breaks daily…"
2. Forms of Retaliation Experienced	Verbal Harassment, Exclusion, Defamation, Transfers, Humiliation	I was removed from the WhatsApp group for no reason. People would go silent when I entered the coffee room.)"Suddenly I was called rude, manipulative… (A story was created against me, labeling me as rude and manipulative.)
3. Barriers to Whistleblowing	Fear of Hierarchy, Career Jeopardy, Cultural Obedience, No Safe Channels	Interns have no authority, nurses are even lower, and experienced ones like me are at the bottom. I was told, 'Be smart. Don't go against the system.'
4. Institutional Silence and Mental Health Apathy	HR Distrust, Gender Disempowerment, Lack of Counseling, Token Policies	The counselor belonged to the HR department. Policies exist on paper, but not in real life. If even female doctors can't speak, how can nurses?
5. Coping and Survival Strategies	Silence, Therapy, Changing Jobs, Advocacy, Emotional Suppression	I went silent. I didn't speak to anyone. I did my work and cried at home. I went to therapy. Later, I started conducting medical ethics training through an NGO.
6. Recommendations for Reform	Anonymous Forums, External Committees, Gender-Sensitive Units, Legal Protection Clauses	There should be a separate department for nurses. Patients and doctors both feel entitled to misbehave. "An anonymous national forum that is active and takes action instantly…" Such a forum would reform the toxic Indian healthcare system.

Discussion

To break a silence that is institutionally enforced and culturally normalized is not just defiance; it is emotional bravery. This chapter begins where the stories end, examining not just what whistleblowers endured but what their experiences reveal about the moral, psychological, and institutional fabric of Indian healthcare. We go beyond reporting events to analyze why and how they occurred, and what they signify. By connecting lived realities, cultural context, and psychological theory, this chapter frames retaliation as systemic failure and personal trauma. It answers research questions, highlights key patterns, and proposes reforms to protect whistleblowers and repair the systems they sought to save.

Research Questions

RQ1: How do whistleblowers in the Indian healthcare sector describe their experiences of retaliation following the exposure of unethical or illegal practices?

Participants described retaliation as subtle yet psychologically damaging, including public humiliation, social ostracism, exclusion from opportunities, and administrative sidelining, framed as deliberate strategies to silence dissent and maintain systemic complicity. These findings align with Bjørkelo (2013)[4] and Vandekerckhove (2006)[40], who view retaliation as normalized and culturally sanctioned. In India, such actions reflect cultural values like hierarchy and authority, supporting Hofstede's (2001)[39] power distance theory and showing institutionally embedded retaliation.

RQ2: What are the emotional and psychological effects of such retaliation on whistleblowers' mental health and well-being?

The psychological impact was profound, with participants reporting anxiety, insomnia, depression, social withdrawal, fatigue, appetite loss, and panic attacks. Shame and isolation were intensified by cultural norms discouraging emotional expression.

RQ3: What coping strategies do whistleblowers employ to manage the stress and trauma associated with retaliation?

Participants used coping mechanisms ranging from emotional withdrawal to proactive resilience; some chose silence, therapy, or job change, while others engaged in advocacy. Coping was self-initiated, with minimal institutional support. Notably, participants found emotional relief simply by being heard, highlighting the therapeutic role of narrative sharing in forensic psychology and showing both resilience and vulnerability.

RQ4: How do whistleblowers perceive the support systems available to them, both within their institutions and externally?

Support systems were largely perceived as inadequate or absent. Participants distrusted institutional mechanisms like grievance committees or in-house counselors, especially those tied to HR. Though protection policies existed on paper, they were rarely implemented. Female staff reported higher vulnerability, highlighting the need for intersectional reforms.

Emerging concepts

Two key concepts emerged: "shame-based silencing," where internalized guilt rooted in cultural obedience prevents whistleblowers from seeking justice; and "learned despair," a state of emotional numbing and resignation caused by repeated institutional neglect. This despair, akin to Seligman's learned helplessness, made participants passive and disengaged. These concepts expand existing theories by integrating cultural dynamics into trauma response, highlighting how systemic injustice shapes psychological withdrawal and silencing.

Interpretation through Theoretical Lenses

Trauma Theory explains the chronic emotional suffering of whistleblowers, where persistent retaliation and lack of justice create a prolonged trauma loop.

Conclusion

This study revealed a culture of retaliation and silence in Indian healthcare, confirming whistleblower trauma as a systemic, culturally embedded issue. Narratives exposed the emotional cost of integrity and lack of institutional support, demanding urgent reform. Most crucially, it highlighted how hierarchy and stigma make whistleblowing both moral and risky. Institutions must view whistleblowers not as threats, but as ethical reformers deserving acknowledgment and institutional responsibility for their psychological harm.

Recommendations and Implications for Theory, Research, and Practice

- Incorporate cultural constructs like power distance, shame, and moral duty into future whistleblower psychology models, moving beyond Western-centric frameworks.
- Establish independent, trauma-informed protection units within healthcare systems to safeguard whistleblowers.
- Train mental health professionals to identify and address whistleblower-related trauma.
- Promote peer-support networks within institutions to offer informal emotional assistance.
- Explore long-term psychological outcomes, sector-specific differences, and the role of online forums in future research to enhance support systems across diverse cultural settings.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Original Article DOI: https://doi.org/10.37506/vsj7sy68

Latent Fingerprint Development on Multiple Surfaces: A Comparative Analysis using Black Sindoor (Black Vermillion), Redsindoor (Red Vermillion), and Sandalwood Powder

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How to cite this article: Vaishnavi Vivek Sawant, Anisha Kudaskar, ThejuKumarC, Anil Kumar. Latent Fingerprint Development on Multiple Surfaces: A Comparative Analysis using Black Sindoor (Black Vermillion), Redsindoor (Red Vermillion), and Sandalwood Powder. Medico-Legal Update / Vol 25 No. 4, October - December 2025

Abstract

The research deals with development of latent fingerprint on different surfaces using commercially available natural powders like red sindoor(red vermillion), black sindoor (black vermillion),and sandalwood. Paper describe new method of developing latent fingerprints using simple and non-toxic powders which are easily available and have variety of domestics and traditional uses. The study is to evaluate how well these powders reveal latent prints on a variety of surfaces using forensic procedures. The research aims to clarify the advantages and disadvantages of each powder type with respect to surface type (Glass surface,lamination sheet, transparencysheet, metal surface,woodensurface, plainpaper, cardboard, plastic, tile, and steel)using methodical experimentation and comparative analysis. It has been observed that the results are positive on almost all the surfaces. Ultimately, this study contributes to enhancing forensic methodologies for latent fingerprint detection and analysis, thereby aiding law enforcement agencies in criminal investigations and justice administration.

Introduction

Impression evidence refers to the impressions left at a crime scene or elsewhere that can be used to identify or link a specific object, tool, or individual to the scene. It includes marks or impressions made by shoes, tires, tools, or other objects, as well as bite marks or marks left by tools on other surfaces[1]. This type of evidence can be crucial in investigations as it can help establish connections between suspects, victims, and crime scenes, and can provide valuable information about the events that occurred[2].

Fingerprints

Fingerprints represent one of the most commonly discovered types of impression evidence at crime scenes. It is considered as the most important type of impression evidence used for identification purpose[3]. The term fingerprint evidence describes the exclusive ridges, grooves, and identifiable patterns located on a person's fingers and palms. These patterns are formed during fetal developmentandremain unchangedthroughout a person'slife,makingfingerprintsareliablemeans of identification[4].

Types of finger print evidence found on the crime Scene

- **Visible prints:** These prints are easily noticeable to the naked eye and are generally formed when substances such as blood, ink, dust, or grease on the fingers come into contact with another surface[7].

Submission: Jul 24, 2025 **Revision:** September 15, 2025 **Published date: September 25, 2025**

- **Plastic Print:**Aplastic print refersto a raised, three-dimensional markcreated when fingerspress into a soft surface.
- **Latent Print:** Latent print are the invisible prints that are not visible to the naked eyes and required tobe developed. These impressions can be present on different types of surfaces,including glass, metal, plastic, and paper.Forensic experts use various methods to reveal latent prints, such as dusting with powder, applying chemical reagents, or using alternative light sources like ultraviolet or infrared light[8].

Methods used in Developing Latent Prints

Latent prints can be developed by using different methods (physical method, chemical method and instrumentation).

- Physicalmethod: Physical method of developing finger prints are the most commonly used method. A fine powder is carefully dusted over the surface suspected to contain latent fingerprints. The powder adheres to the oily residue left behind by the friction ridges of the skin, making the latent print visible.
- Chemical method: chemical method is anothere ffective method for development of latent finger print son different surfaces using chemicals. The semethods involve the application of specific chemicals that react with the components of the fingerprint residue, making the latent print visible
- Istrumentation Method: Instrumentation method involves using different techniques and instruments for development of latent print. These methods offer advantages such as increased sensitivity, precision, and the ability to detect prints on challenging surfaces.

Importance of Finger Print Development

The discovery of fingerprints at a crime scene can aid in both establishing a suspect's involvement and excluding individuals who are not connected to the incident. The uniqueness and permanenceof fingerprint patterns make them invaluable in establishing identity, aiding law enforcement agencies in solving crimes, proving innocence, and ensuring the fair administration of justice. Additionally, the development of fingerprints provides crucial evidence in court proceedings, helping to convict perpetrators and uphold the rule of law. Since fingerprint technology was developed, it has greatly aided in case solving and is still regarded as the most reliable way to identify the offender[9].

Importance of Using Commercially Available Natural Powders

Natural powders are easily available in market and are non-toxic compare to chemical powders. Commercial powders have various traditional uses. The chemical powders that are available is market have adverse effects on health as it contains chemicals. The commercially available powders are non-toxic and are easily available. The commercially available powders are cheap compare to the chemical powders[10].

Data Collection

Fingerprint samples were obtained from local people, with a total of 10 individuals participating in the study. Proper consent was taken from all the participants before the collection process. The primary objective of the study is to examine whether the collected fingerprints can be successfully developed using fingerprint powders.

Methodology

The present study focus on development of latent prints using commercially available natural powders in replacement of chemical powders. Commercially available powders are non-toxic and are easily available compare to chemical powders.

Materialsand Methods

1. **Selection of surface:**

   Different types of surfaces were used for latent print development such as plastic, Wood,

plain paper, steel, metal, Lamination sheet, cardboard, transparency sheet, Glass, and Tile.

2. **Powder Preparation:**
Commercially available Red sindoor powder (Red vermillion)were taken and ground in theblender until fine powder is obtained. The prepared powder is stored in test tubes and the test tubes were sealed. Also the room temperature was maintained. Same procedure was followed for Black sindoor (black vermillion) and Sandalwood powder.

3. Latent Finger print development:

- To visualize latent fingerprints, prepared powders (Red Sindoor, Black Sindoor, and Sandalwood)were applied to ten different surfaces, namely plastic, wood, plain paper, steel, metal, lamination sheets, cardboard, transparency sheets, glass, and tiles.
- Anostrich feature brush was used to apply powder on the surface containing latent print.
- Once the latent print was developed photograph of the print was taken for analysis.
- The finger print was collected using adhesive tape. The fingerprint was later preserved by affixing the tape containing the developed print onto a lifting card.
- At last the print was compared to each other based on the clarity of the print on different surfaces.

Latent Finger Prints Developed using Red Sindoor Powder (Red Vermillion) On Different Surfaces

Glass Surface

Lamination Sheet

Transparency Sheet

Metal Surface

Wooden Surface

Plain Paper Surface

Cardboard Surface

Plastic Surface

TileSurface

Steel Surface

Latent Finger Prints Developed using Black Sindoor Powder (Black Vermillion) Ondifferent Surfaces

Glass Surface

Lamination Sheet

Transparency Sheet

Metal Surface

Wooden Surface

Plain Paper Surface

Cardboard Surface

Plastic Surface

Tile Surface

Steel Surface

Latent Finger Prints Developed using Sandal Wood Powder on Different Surfaces

Glass Surface

Lamination sheet

Transparency sheet

MetalSurface

WoodenSurface

Plain Paper Surface

Cardboard Surface

Plastic Surface

Tile Surface

Steel Surface

Data Analysis

Table 1. Development of latent finger print using Red Sindoor powder (Red Vermillion)

Surface	Development
Glass	Developed
Laminationsheet	Developed
Metal	Developed
Tile	Developed
Cardboard	Developed
Transparency sheet	Developed
Steel	Developed
Plain paper	Developed
Wood	Developed
Plastic	Developed

Table 2. Development of latent finger print using Black Sindoor Powder (Black Vermillion)

Surface	Development
Glass	Developed
Laminationsheet	Developed
Metal	Developed
Tile	Developed
Cardboard	Developed
Transparency sheet	Developed
Steel	Developed
Plain paper	Developed
Wood	Developed
Plastic	Developed

Table 3. Development of latent finger print using Sandal wood Powder

Surface	Development
Glass	Developed
Laminationsheet	Developed
Metal	Developed
Tile	Developed
Cardboard	Developed
Transparency sheet	Developed
Steel	Developed
Plain paper	Developed
Wood	Developed
Plastic	Developed

Comparison

The fingerprints were successfully developed on all the tested surfaces using three different powders: black powder (Black Vermillion), red sindoor(Red Vermillion), and sandalwood powder. In general, the ridge patterns were clearly visible across most surfaces, demonstrating the effectiveness of all three development techniques. However, certain limitations were observed during the process. Specifically, when red sindoor and sandalwood powder were used on cardboard surfaces, the ridge details were not as distinct compared to other surfaces, indicating reduced clarity or incomplete development. Additionally, on plain paper, the fingerprints developed with sandalwood powder appeared slightly smudged, which could be attributed to the texture or absorbent nature of the paper affecting the powder's adherence.

Major Findings

Red Sindoor powder (Red Vermillion)

The latent fingerprints developed using red sindoor powder showed successful results on most ofthe surfaces tested. Red sindoor, being a fine powder with bright coloration, provided good contrast against various backgrounds, allowing the ridge patterns of the fingerprints to become visible. The powder adhered effectively to the sweat and oily residues left by the fingerprint, resulting in clear development of ridgedetails on non-porous and semi-porous surfaces. However, the performance of red sindoor was not consistent across all materials. On cardboard surfaces, the finger prints developed using red sindoor were not as clear or defined. This is primarily due to the absorbent nature of cardboard, which tends to soak up the moisture and sweat present in the finger print residue. As a result, the ridge patterns become diffused or faded within the surface layers, preventing the red sindoor powder from properly adhering to and highlighting the finger print details. Therefore, while red sindoor proved to be an effective and easily available agent for developing latent prints on several surfaces, its performance was limited on porous materials like cardboard where the absorption of fingerprint residue reduced the clarity of the developed impressions.

Black Sindoor Powder (Black Vermillion)

The use of black sindoor powder for developing latent fingerprints yielded successful results on all examined surfaces. Black sindoor, known for its fine consistency and dark shade, provided excellent visibility of ridge patterns, even on surfaces with varying textures and colors. Thepowder adhered effectively to the moisture, natural oils, and residues left by the fingertips, making the finger print impressions stand out with good clarity. An important observation was that black sindoor performed consistently across both porous and non-porous surfaces. Even on challenging materials like cardboard, where fingerprint development is often difficult due to the surface absorbing sweat and other residues, black sindoor produced clear and distinguishable ridge details. Its strongcontrast and good sticking properties allowed the ridge patterns to be developed without smudging or loss of detail. The overall findings suggest that black sindoor is a reliable and affordable option for developing latent fingerprints, offering consistent results on different types of surfaces.

Sandalwood Powder

The development of latent fingerprints using sandalwood powder showed positive results on all tested surfaces, as the powder successfully revealed fingerprint impressions across different materials. Sandalwood powder, being finely ground and light in color, offered reasonable contrast, especially on darker backgrounds. It adhered to the residues left by the fingerprint, allowing the ridge patterns to become visible. However, certain limitations were noted during the process. On plain paper and cardboard surfaces, the developed fingerprints were not clear and appeared smudged. This can be attributed to the porous and absorbent nature of both materials. Surfaces like paper and cardboard tend to absorb the moisture, sweat, and oils from the fingerprint before the development process, causing the ridge

details to diffuse into the surface layers. As a result, when sandalwood powder was applied, it could not settle accurately on the ridge structures, leading to smudging and unclear impressions. Despite these limitations on porous surfaces, sandalwood powder proved to be an effective and natural alternative for fingerprint development, showing satisfactory results on most surfaces, particularly non-porous and semi-porous materials where better clarity was achieved.

Discussions

The present study evaluated the effectiveness of red sindoor powder, black sindoor powder, and sandalwood powder as locally available agents for latent fingerprint development on different surfaces. The findings demonstrate that each of the tested powders exhibited distinct advantages and limitations depending on the surface type.

Red sindoor powder showed good contrast and clear fingerprint ridge details on non-porous and semi-porous surfaces, but its effectiveness decreased on porous surfaces like cardboard. This observation aligns with previous studies (Cadd et al., 2015; Lee &Gaensslen, 2014), which reported that powders generally produce better results on smooth, non-porous substrates due to the oily substance that retents the residues. The inability of red sindoor to produce clear impressions on porous surfaces is consistent with the general challenge faced when developing fingerprints on absorbent materials.

In comparison, black sindoor powder performed consistently across all surfaces, including porous ones such as cardboard. Its fine texture and strong color contrast appear to enhance adhesion to fingerprint residues, enabling the visualization of ridge details with minimal smudging. These results are comparable to those obtained with standard black fingerprint powders, which have long been considered reliable for diverse surfaces (Saferstein, 2021; Champod et al., 2016). The consistency of black sindoor across porous and non-porous materials suggests that it may serve as a cost-effective alternative to commercially available powders in forensic casework.

Sandalwood powder also proved effective, particularly on non-porous and semi-porous surfaces, where satisfactory ridge clarity was observed. However, its performance on paper and cardboard was limited due to diffusion of fingerprint residues into the absorbent surface, resulting in smudged impressions. Similar limitations with light-colored powders on porous surfaces have been reported in earlier research (Fieldhouse, 2011; Cadd et al., 2015). Despite this drawback, sandalwood powder's natural origin and accessibility make it a potential eco-friendly option for fingerprint development.

Overall, the comparative findings indicate that black sindoor powder offered the most consistent and reliable performance across different surface types. Red sindoor and sandalwood powders demonstrated promising results on non-porous materials but were less effective on porous surfaces, a limitation widely acknowledged in prior fingerprint development studies. These findings reinforce the importance of surface characteristics in fingerprint development and support the use of sindoor powders, particularly black sindoor, as affordable and accessible alternatives to conventional forensic powders.

Conclusion

The present research highlights the effectiveness of easily available household powders—red sindoor, black sindoor, and sandalwood powder—in the development of latent fingerprints on various surfaces. Among the three, black sindoor demonstrated the most consistent results, successfully developing clear and visible ridge patterns on all tested surfaces, including porous materials like cardboard. Red sindoor also proved effective on most surfaces but showed reduced clarity on cardboard due to the absorbent nature of the material, which limits proper powder adherence. Sandalwood powder, though capable of developing prints on all surfaces, displayed certain limitations, especially on plain paper and cardboard, where the finger prints appeared smudged and the ridge details lacked definition. The findings suggest that while all three powders havepotential forlatent fingerprint

development, the surface text ure and porosity play a crucial role in the clarity and quality of the developed prints. Among the materials tested, black sindooremerged as the most reliable option for both porous and non-porous surfaces, making it a practical and cost-effective alternative in situations where conventional fingerprint powders are unavailable. This research demonstrates the feasibility of using readily available household materials in forensic fingerprint development, while also emphasizing the need to select development agents based on surface characteristics to achieve optimal results.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Original Article DOI: https://doi.org/10.37506/3brh4j59

Developing Latent Fingerprints from Surface of Eggshell using Physical Methods

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How to cite this article: Nithin S, Swapna Gowri C S, Sona Mariya. Developing Latent Fingerprints from Surface of Eggshell using Physical Methods. Medico-Legal Update / Vol 25 No. 4, October - December 2025

Abstract

The development of latent fingerprints on unconventional surfaces, such as eggshells, presents unique challenges due to their fragile and porous nature. This study focuses on evaluating the effectiveness of two physical methods—black powder and fluorescent powder—in developing latent fingerprints on eggshell surfaces under both normal conditions and when covered with plastic bubble wrap. A total of ten samples were tested for each condition. Results indicate that black powder consistently produced better fingerprint contrast, with five samples showing excellent visibility under normal conditions and moderate success even under plastic wrap. In contrast, fluorescent powder demonstrated poor performance overall, with no samples displaying excellent contrast and a significant number yielding weak or no visibility, especially when surface conditions were altered by plastic covering. The findings suggest that black powder is more suitable for fingerprint development on eggshell surfaces, while fluorescent powder is limited in its effectiveness, particularly under textured or wrapped conditions. This study highlights the importance of selecting appropriate physical methods for latent print development on delicate biological surfaces.

Keywords: Latent fingerprint, Egg shell, Black powder, fluorescent powder, Plastic bubble wrap

Introduction

Fingerprints are patterns made up of ridges and furrows on the finger tips. Fingerprints are part of biometrics, which is the study of identifying people based on their physical characteristics.[1,2] Fingerprints are ideal for this purpose since they are inexpensive to obtain and analyze, and they do not change with age.[1] Fingerprints are a natural, distinctive pattern generated by disunion on epidermal crests and furrows that emerge on the pads of the fingers and thumbs.[1,2] Although these epidermal crests are located on the fingers, palms, and soles, they are commonly referred to as fingerprints.[1] They have never been observed to repeat in any mortal entity in the history of dactylography.[1] Fingerprints are sometimes termed dactylograms.[1]

A person's fingerprint is produced based on two factors: genetics from parents and the state of the baby in the mother's womb.[2] The patterns indicate that two people are related because they share various physical characteristics, such as facial features or hair color. This is because children inherit half of their DNA (genetic blueprints) from both parents.[2] Fingerprints are used to identify persons because each person's fingerprint is unique; nevertheless, people can have similar fingerprint

Submission: Jul 10, 2025 **Revision:** August 25, 2025 **Published date: September 25,2025**

patterns. Whether fingerprint patterns are random or influenced by heredity.[2]

Fingerprints are unique patterns of ridges and furrows on the fingertips, formed by the separation of epidermal crests, and are commonly referred to as dactylograms.[1] Though similar patterns may occur among family members due to genetic influence, each individual's fingerprints are distinct, shaped by both heredity and fetal development conditions.[2] These patterns are permanent and have never been found to repeat in any two individuals, making fingerprints a reliable means of identification.[1,2] Their uniqueness and stability have led to their widespread use in forensic science, biometric security, and identity verification, playing a crucial role in law enforcement, border control, and cybersecurity in modern society.[1,2,3]

Fingerprint identification has ancient roots, with early uses traced back to Babylon around 2000 BCE for business transactions on clay tablets and to ancient China, where thumbprints were used as signatures under the Qin Dynasty.[1] But these practices were not based at the time on scientific knowledge of the uniqueness of fingerprints. In the 17th century, European anatomists such as Nehemiah Grew and Marcello Malpighi began to examine skin ridge patterns, although the forensic value was not appreciated for centuries.[1] Contemporary fingerprinting began in the nineteenth century, when Sir William Herschel used fingerprints as a technique of identification in India in the 1850s.[1] Dr. Henry Faulds later recommended its use in criminal investigations,[4] while Sir Francis Galton's 1890s research provided scientific verification of fingerprints' uniqueness and permanence.[1] Sir Edward Henry expanded on Galton's work, creating a classification system that was later used by British India and Scotland Yard.[1] Fingerprinting became regular forensic science at the turn of the twentieth century, revolutionizing personal identification and crime investigation around the world.[1,2]

Methodology

Aim

This study is intended to identify effective ways of fingerprint development and visualization on Surface of eggshells that may expand the variety of forensic evidence.

Objectives

1. To evaluate the effectiveness of various physical techniques, i.e., powder dusting, for the development of latent fingerprints on eggshells
2. To identify the efficiency of physical methods in recovering latent fingerprints from eggshells under various conditions.
3. To optimize the developed methods for enhancing the quality of latent fingerprints recovered from eggshells.
6. To explore the potential applications of the developed methods in forensic science, particularly in the investigation of crimes involving eggshells or other fragile evidence.
7. To optimize the developed methods for enhancing the durability of latent fingerprints recovered from eggshells.

Research Question/Problem Statement

1. How effective are different physical methods particularly powder dusting in developing the latent fingerprints on egg shell surfaces?
2. What modifications to existing physical methods can improve the clarity and ridge details of latent fingerprints recovered from egg shells?
3. How does the effectiveness of black powder compared to fluorescent powder in developing and visualizing the latent fingerprints on egg shell surfaces under different environmental conditions?

Research Design

For this study the purposive and experimental study design will be employed.The type of research design is sampling method.

Universe, Sample Size, Sampling Techniques

For this study, researcher has collected samples of 10 under each condition with the informed consent

from the participants. The study conducted in Kerala, Ernakulam.

Materials Required

1. Egg
2. Black powder
3. Fluorescent powder
4. Feather brush
5. Cello tape
6. OHP sheet
7. Tissue paper
8. Plastic wrapper
9. Magnifying lens

Procedure

- The fingerprint has been deposited on the surface of the egg. And the prints have been suspendedunder two different conditions: normaland plastic wrap. The samples under each condition are been developed and examined in the following ways,
- The black and fluorescent powder was applied to each surface to produce the fingerprint using a feather brush. The researchers had applied the powder to the surface where the fingerprint has been deposited. The fingerprint became apparent to the human eye shortly after its creation. Excessive powders are removed, and the developing area's surroundings are cleansed. Use a camera lens to photograph the print. The print has been lifted using cellophane tape and adhered to the OHP sheet. The fingerprint's quality was then assessed using the Magnifying lens.
- The quality of the fingerprint has been examined under the following grades and contrasts

Grade	Friction Ridge Detail	Contrast
0	No development	No contrast
1	<1/3 of continuous ridge detail, some evidence of contact.	Poor contrast
2	1/3-2/3 of the developed fingermark is continuous ridge detail.	Moderate contrast
3	>2/3 of the developed fingermark is continuous ridge detail.	Good contrast
4	Full development; whole fingermark visible with continuous ridges.	Excellent contrast

Observation

Observation under normal condition of surface of the egg shell

Table1. Observed Contrast in Different Samples by using Black Powder

SAMPLE NO	OBSERVED CONTRAST
Sample 1	Excellent contrast
Sample 2	Excellent contrast
Sample 3	Excellent contrast
Sample 4	Good contrast
Sample 5	Moderate contrast
Sample 6	Moderate contrast
Sample 7	Good contrast
Sample 8	Excellent contrast
Sample 9	Excellent contrast
Sample 10	Moderate contrast

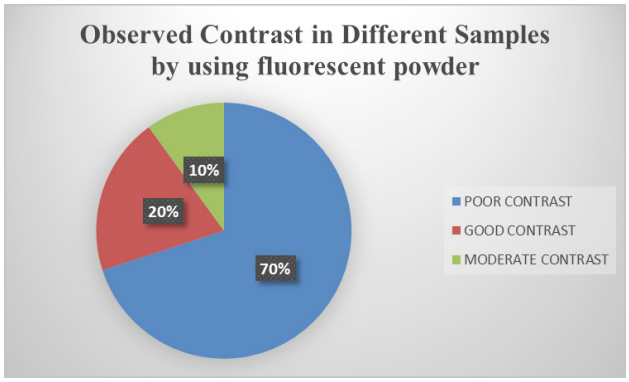

Figure 1: Observed contrast in different samples by fluorescent powder

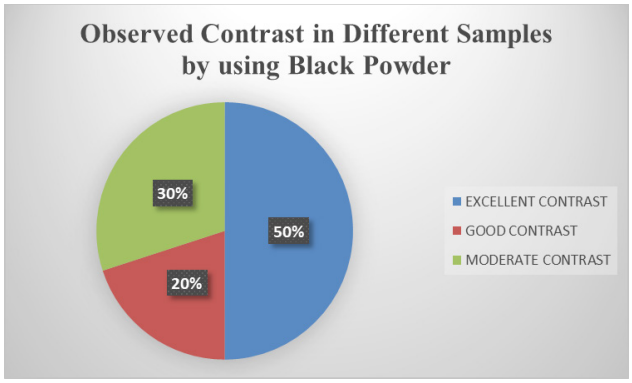

Figure 2: Observed contrast in different samples by black powder

Table 2. Observed Contrast in Different Samples by using fluorescent powder

SAMPLE NO	OBSERVED CONTRAST
Sample 1	Poor contrast
Sample 2	Poor contrast
Sample 3	Good contrast
Sample 4	Good contrast
Sample 5	Poor contrast
Sample 6	Poor contrast
Sample 7	Moderate contrast
Sample 8	Poor contrast
Sample 9	Poor contrast
Sample 10	Poor contrast

Observation under plastic bubbled wrap condition of surface of the egg shell

Table 3. Observed Contrast in Different Samples by using Black Powder

SAMPLE NO	OBSERVED CONTRAST
Sample 1	Moderate contrast
Sample 2	Moderate contrast
Sample 3	Excellent contrast
Sample 4	Poor contrast
Sample 5	Good contrast
Sample 6	Poor contrast
Sample 7	Poor contrast
Sample 8	Moderate contrast
Sample 9	Excellent contrast
Sample 10	Good contrast

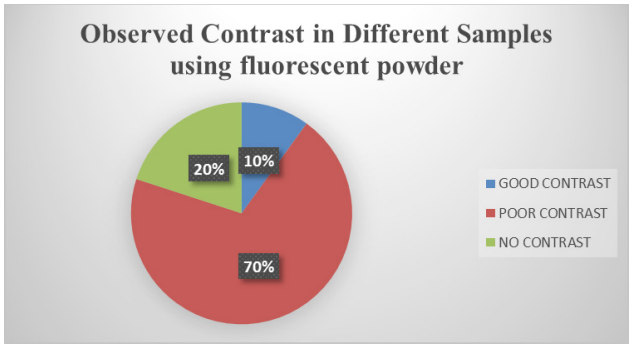

Figure 3: Observed contrast in different samples by fluorescent powder

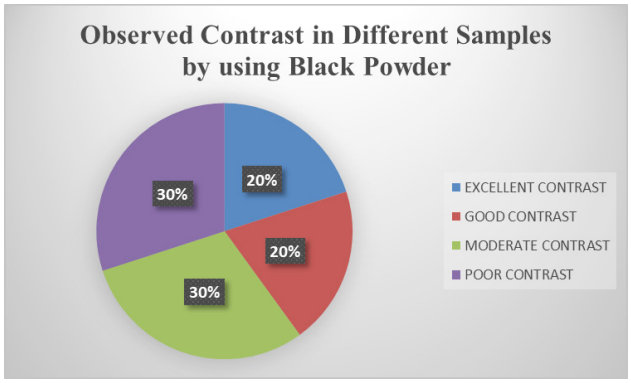

Figure 4: Observed contrast in different samples by black powder

Table 4. Observed Contrast in Different Samples using fluorescent powder

SAMPLE NO	OBSERVED CONTRAST
Sample 1	Poor contrast
Sample 2	Poor contrast
Sample 3	Good contrast
Sample 4	No contrast
Sample 5	Poor contrast
Sample 6	Poor contrast
Sample 7	Poor contrast
Sample 8	No contrast
Sample 9	Poor contrast
Sample 10	Poor contrast

Major Findings

- Under normal circumstances, black powder produced the most excellent contrast results, with 5 out of 10 samples displaying exceptional fingerprint visibility.

- Under normal circumstances, the fluorescent powder produced substantially less favourable results; none of the samples displayed exceptional clarity, and 7 out of 10 merely produced poor contrast.
- Black powder's performance decreased when exposed to plastic wrap; only the two samples (3 and 9) demonstrated exceptional contrast when compared to 5 under normal circumstances, suggesting wrap interference.
- Under plastic wrap, fluorescent powder did the poorest; two samples (4 and 8) showed no contrast at all, while the majority (7 out of 10) showed weak contrast.
- Under both circumstances, black powder continuously dominated fluorescent powder, generating more excellent, good, and moderate contrasts.
- Regardless of surface condition, fluorescent powder results showed moderate to poor contrasts, indicating that it is less appropriate for eggshell surfaces than black powder.
- Under plastic wrap, black powder still provided some usable results (e.g., good or moderate) in 6 samples, whereas fluorescent powder yielded only one good contrast (Sample 3).
- The application of plastic bubble wrap significantly reduced the contrast quality, especially for fluorescent powder, likely due to texture interference or reduced powder adherence.
- Overall, black powder is more reliable for fingerprint development on eggshell surfaces, while fluorescent powder showed limited applicability, especially under altered surface conditions like wrapping.

Recommendation and Suggestion of The Study

1. **Prefer Black Powder for Eggshell Surfaces**: Given its consistently higher contrast results, black powder should be the primary choice for fingerprint development on eggshell surfaces under normal conditions.
2. **Avoid Fluorescent Powder for Eggshells**: The overall weak and inconsistent performance of fluorescent powder suggests it is not suitable for use on eggshell surfaces, especially where high clarity is required.
3. **Minimize Use of Plastic Bubble Wrap**: Plastic wrapping negatively impacts fingerprint visibility, particularly with fluorescent powder. Avoid wrapping evidence surfaces if preservation without distortion is possible.
4. **Further Investigate Wrap-Induced Interference**: The significant drop in contrast under plastic wrap, especially for fluorescent powder, warrants further study into the nature of texture interference or powder adherence issues.
5. **Standardize Handling Procedures**: Implement guidelines to maintain natural surface conditions during collection and examination of delicate surfaces like eggshells to preserve fingerprint integrity.
6. **Explore Alternative Powders or Methods**: Future research should explore other finger print development techniques (e.g., cyanoacrylate fuming or magnetic powders) to improve results on challenging surfaces like eggshells.
7. **Use Fluorescent Powder with Caution**: If fluorescent powder must be used, it should be restricted to smoother, non-porous surfaces, and not on fragile or irregular textures like eggshells.
8. **Train Forensic Personnel Appropriately**: Ensure that forensic professionals are well-trained in selecting and applying appropriate powders depending on surface type and condition to optimize evidence recovery.

Discussion

The present study aimed to evaluate the effectiveness of black powder and fluorescent

powder in developing latent fingerprints on eggshell surfaces under normal and plastic wrap conditions. The results clearly indicate that black powder consistently produced higher quality contrasts compared to fluorescent powder, both under direct application and when surfaces were altered by plastic covering.

These findings are consistent with previous research which emphasizes the versatility and reliability of conventional black powders on non-porous and semi-porous substrates. Sodhi & Kaur[8], highlighted that carbon-based powders adhere effectively to sweat and oily residues, providing clear ridge details in most practical forensic conditions. Similarly, Moreno et al.[14] demonstrated that the chemical composition of black powders contributes to strong adherence and stable contrast, making them a robust option even when surface texture presents challenges.

By contrast, fluorescent powders—while highly sensitive and effective on smooth, reflective, or colored surfaces—show limitations on irregular or porous substrates. Boonyaras et al.[7] and Bhati et al.[13] both observed that fluorescent substances require optimal surface-sample compatibility to yield satisfactory ridge detail. This aligns with the present findings, where eggshells' porous and fragile nature hindered the adherence of fluorescent particles, resulting in weak or no contrast in most cases, particularly under plastic wrapping.

The interference caused by plastic wrap further reduced the visibility of ridge details, suggesting that surface modifications significantly impact powder adherence. Previous studies have also noted that external coverings or textured substrates create additional barriers for fluorescent powders compared to traditional carbon-based powders. Qiu et al.[6], Abebe et al. [15], In this study, black powder still produced moderate to good contrasts in several samples under wrapped conditions, reinforcing its reliability, whereas fluorescent powder largely failed to provide usable results.

An important contribution of this research is its focus on eggshell surfaces, which represent delicate biological substrates rarely investigated in forensic practice. Prior work on unusual or porous surfaces, such as paper, supports this observation. O'Neill[5], ; Pounds et al. [5], Our results confirm that eggshells, like other porous surfaces, are poorly suited for fluorescent powder application but respond adequately to traditional black powder dusting.

Moreover, the reproducibility of fingerprint features plays a critical role in forensic reliability. Studies on fingerprint microfeatures and pore-level analysisPreethi et al. [12], emphasize the importance of clarity and continuous ridge detail for valid comparison. In this context, black powder's ability to consistently yield clear ridge continuity, even under less-than-ideal conditions, makes it superior for fragile substrates like eggshells.

An important aspect of fingerprint analysis lies in micro- and third-level features such as sweat pores and ridge edge details. Woo and Park[10], demonstrated that sweat pore mapping using polymer-based films could significantly enhance fingerprint visualization, emphasizing the value of pore-level information for identification. Similarly, Parsons et al.[11], introduced rotationally invariant statistical models to objectively evaluate pore features, highlighting their forensic relevance. Although our study primarily evaluated ridge contrast, the observed limitations of fluorescent powder on eggshells suggest that future research could incorporate pore-focused techniques to improve evidentiary value.

Overall, this study contributes to forensic science by demonstrating that conventional black powder remains the most reliable method for fingerprint visualization on eggshell surfaces, whereas fluorescent powders should be applied with caution, restricted to smoother non-porous substrates. These findings are in line with prior reviews Sodhi & Kaur[8], Abebe et al. [15], which recommend tailoring powder selection to the nature of the substrate to maximize evidential recovery.

Conclusion

For the above study the researchers would like to conclude, Based on the comparative analysis

of black and fluorescent fingerprint powders on eggshell surfaces under normal and plastic bubble wrap conditions, it is evident that black powder consistently outperforms fluorescent powder in terms of contrast and clarity. Under normal circumstances, black powder yielded excellent results in half the samples, while fluorescent powder failed to produce any exceptional contrasts, with the majority showing poor quality. The effectiveness of both powders declined when plastic wrap was applied, but black powder still maintained a moderate level of usability, whereas fluorescent powder performance deteriorated significantly, with several samples showing no contrast at all. This indicates that plastic wrap interferes with powder adherence, particularly affecting fluorescent powders more severely. Overall, the study concludes that black powder is a more reliable and effective medium for developing fingerprints on delicate surfaces like eggshells, and fluorescent powder should be avoided in such contexts, especially when surface conditions are altered by wrapping.

Funding: Nil

Ethical Clearance/Statement of Ethics: Nil

Conflict of Interest: nil

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