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TRACING THE TRUTH: PRESERVATION AND DOCUMENTATION OF TOOLMARK EVIDENCE IN FORENSIC INVESTIGATIONS

AUTHOR - VANMATHI N, STUDENT AT TAMILNADU DR. AMBEDKAR LAW UNIVERSITY

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CHAPTER-1

1.1 Introduction

In the realm of forensic science, toolmarks, the impressions or scratches left by tools on surfaces, are among the most compelling forms of physical evidence. Whether in cases of burglary, sabotage, or homicide, these marks can link a specific tool to a crime scene through unique wear patterns and microscopic imperfections. This ability to individualize a tool makes toolmarks powerful in criminal investigations[987]. Yet, despite their evidentiary strength, toolmarks often receive less attention than fingerprints or DNA, even though they can help reconstruct events and reveal criminal intent.

In India, the significance of toolmarks has gained renewed focus with the enactment of the Bharatiya Nagarik Suraksha Sanhita 2023, which replaces the colonial-era Criminal Procedure Code. Under Section 106 of the BNSS, physical evidence like toolmarks must be scientifically documented and preserved to be admissible in court[988]. This aligns with Article 21 of the Constitution, which guarantees due process and procedural fairness in criminal trials[989].

Preserving toolmarks depends on the surface and type of mark. Common methods include high-resolution photography, silicone-based casting, and electrostatic lifting. Documentation, on the other hand, involves structured forensic reports, laboratory comparisons, and crime scene sketches. These practices are expected to follow international standards such as those set by the Association of Firearm and Toolmark Examiners[990] and ISO 17025 accreditation protocols [991].

However, challenges persist. Many regional forensic labs in India lack access to advanced tools like 3D laser profilometers, and inconsistencies in documentation can jeopardize the integrity of evidence. Moreover, the absence of a centralized toolmark database hampers case comparison and judicial consistency. Addressing these gaps is not just a matter of forensic precision, it is essential for upholding constitutional justice and human rights, especially in custodial investigations.

This study explores the legal admissibility of toolmarks under the BNSS and the Bharatiya Sakshya Adhiniyam[992], critically evaluates current scientific practices for their preservation and documentation, and proposes reforms based on comparative legal systems. Strengthening the role of toolmarks in forensic reconstruction and courtroom decision-making requires standardized protocols, digital preservation, and greater judicial awareness.

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[987] Peterson, J., & Sommers, I. (2010). *Forensic Evidence and Criminal Justice: Toolmarks and Their Role in Investigations*. Journal of Forensic Sciences, 55(2), 345–356

[988] Bharatiya Nagarik Suraksha Sanhita, 2023, Section 106. Government of India Gazette Notification.

[989] Constitution of India, Article 21 – Protection of Life and Personal Liberty.

[990] Association of Firearm and Toolmark Examiners (AFTE). (2023). *AFTE Glossary and Standard Protocols for Toolmark Examination*. AFTE Journal, 55(3), 210–225.

[991] ISO/IEC 17025:2017. *General Requirements for the Competence of Testing and Calibration Laboratories*. International Organization for Standardization; UK Forensic Science Regulator. (2024). *Codes of Practice and Conduct for Forensic Science Providers*.

[992] Bharatiya Sakshya Adhiniyam, 2023. Government of India Gazette Notification. → Governs admissibility of evidence in Indian courts, including toolmarks.

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1.2 Aim and Objectives

- To examine the admissibility, preservation, and documentation of toolmark evidence under BNSS (2023) and BSA (2023), and assess their implications for constitutional justice and victim-centered investigations.
- To analyze statutory provisions governing toolmark admissibility in criminal trials.
- To compare Indian practices with international forensic standards (AFTE, ISO 17025, UK guidelines).
- To evaluate scientific methods for toolmark preservation and documentation, including photography, casting, electrostatic lifting, and 3D profilometry.
- To study judicial precedents highlighting evidentiary value and chain of custody lapses.
- To identify gaps in forensic infrastructure, documentation, and database systems.
- To propose reforms for standardized protocols, digital archiving, and judicial awareness.
- To assess how improved practices can strengthen Article 21 guarantees and victim-centered justice.

1.3 Review of Literature

- Toolmarks are recognized as distinctive physical evidence capable of linking a specific tool to a crime scene through microscopic imperfections and wear patterns.
- **Peterson & Sommers (2010):** Foundational study highlighting toolmarks' evidentiary strength in reconstructing events and revealing criminal intent, though they often receive less attention than fingerprints or DNA.
- **AFTE (2023):** Established the *Theory of Identification*, which defines "sufficient agreement" between questioned and test marks.
- **ISO 17025 & UK Forensic Science Regulator (2024):** Stress reproducibility, metadata integrity, and traceability in forensic documentation.
- Preservation techniques in literature:
  - High-resolution photography (macro lenses, oblique lighting)
  - Silicone-based casting compounds (Mikrosil, AccuTrans)
  - Electrostatic and gel lifting for shallow/fragile marks
- Emerging methods: 3D profilometry and photogrammetry enhance visualization and courtroom presentation.
- In India, scholarship on toolmarks has historically been limited, with forensic research focusing more on fingerprints, DNA, and ballistics.
- **BNSS, 2023 (Section 106):** Mandates scientific preservation and chain of custody documentation.
- **BSA, 2023 (Sections 45 & 63):** Recognizes expert testimony and digital records if validated and metadata intact (Singh, 2024).
- *State v. Ramesh Kumar (AIR 2024 SC 1189)*: Toolmark casts accepted as decisive evidence.
- *State v. Arunachalam (2024)*: Toolmark evidence excluded due to chain of custody lapses.

1.4 Research Problem

Toolmarks can strongly link a tool to a crime scene, yet their forensic and judicial use in India remains underdeveloped. While international standards emphasize protocols such as high-resolution photography, silicone casting, electrostatic lifting, and ISO 17025 accreditation,

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Indian laboratories face infrastructural gaps, inconsistent practices, and a lack of centralized databases. The BNSS (2023) and BSA (2023) provide statutory recognition, Section 106 mandating scientific preservation and Section 45 permitting expert testimony but challenges like inadequate training, poor documentation, environmental degradation, and chain of custody lapses compromise reliability. Judicial precedents (State v. Ramesh Kumar, 2024; State v. Arunachalam, 2024) illustrate how proper preservation strengthens probative value, while lapses nullify it. The core research problem lies in the absence of standardized, scientifically validated, and legally robust protocols for toolmark preservation and documentation in India. This gap raises concerns about forensic reliability, judicial consistency, and constitutional guarantees of fair trial under Article 21, necessitating comparative evaluation of global best practices and reforms integrating forensic science with constitutional justice.

1.5 Research Questions

1. How are toolmarks currently preserved and documented in forensic practice in India, and to what extent do these practices align with international standards such as AFTE protocols and ISO 17025 accreditation?
2. What challenges and limitations affect the reliability and admissibility of toolmark evidence in Indian courts, particularly in relation to fragile substrates, environmental degradation, and chain-of-custody lapses?
3. How have statutory reforms under the Bharatiya Nagarik Suraksha Sanhita (BNSS, 2023) and the Bharatiya Sakshya Adhiniyam (BSA, 2023) influenced the legal recognition and admissibility of toolmark evidence?
4. What lessons can India draw from comparative legal systems and international forensic practices to strengthen the preservation, documentation, and judicial use of toolmark evidence?
5. In what ways can standardized protocols, digital preservation methods, and judicial awareness programs enhance the constitutional guarantee of fair trial under Article 21 when toolmark evidence is presented in court?

1.6 Research Hypothesis

"The absence of standardized, scientifically validated, and legally robust protocols for toolmark preservation and documentation in India, despite statutory recognition under the Bharatiya Nagarik Suraksha Sanhita,2023, and the Bharatiya Sakshya Adhiniyam 2023, significantly undermines the reliability, admissibility, and constitutional value of toolmark evidence in criminal trials. Adoption of international best practices, digital preservation methods, and judicial awareness programs will enhance forensic reliability and strengthen the constitutional guarantee of fair trial under Article 21."

1.7 Research Methodology

Qualitative and Doctrinal Approach: Examines statutory provisions (BNSS, BSA, Constitution of India) and judicial precedents related to toolmark evidence.

Comparative Analysis: Integrates international forensic standards (AFTE Theory of Identification, ISO 17025, UK Forensic Science Regulator guidelines) with Indian statutory reforms.

Exploratory Dimension: Identifies gaps in Indian forensic practice and evaluates reforms needed for the admissibility and reliability of toolmarks.

1.8 Scope and Limitation

Scope

- Examines toolmark admissibility under BNSS (2023) and BSA (2023).
- Reviews preservation/documentation methods including photography,

casting, electrostatic lifting, and emerging 3D technologies.

- Compares Indian practices with international standards (AFTE, ISO 17025, UK guidelines).
- Evaluates judicial precedents (State v. Ramesh Kumar; State v. Arunachalam).
- Contributes by bridging global forensic scholarship with India's statutory reforms, emphasizing constitutional justice and victim-centered investigations.

Limitations

- Resource constraints: lack of advanced equipment in Indian labs.
- Absence of centralized toolmark databases.
- Environmental degradation of fragile substrates.
- Inconsistent documentation and chain of custody practices.
- Limited Indian scholarship compared to fingerprints, DNA, and ballistics.

1.9 Scheme of Study

- The FIRST CHAPTER provides an introduction to the study, setting out the background and significance of toolmarks as forensic evidence. It outlines the aims and objectives, the research problem, research questions, hypothesis, methodology, and scope and limitations.
- The SECOND CHAPTER deals with the classification of toolmarks, explaining the three major types: impression marks, striated marks, and combination marks. It discusses their forensic relevance, methods of identification, and admissibility in court under BNSS and BSA provisions, while also integrating international standards such as the AFTE Theory of Identification.
- The THIRD CHAPTER focuses on preservation techniques of toolmarks, providing a detailed account of scientific methods including high-resolution photography, casting and molding, electrostatic and gel lifting, and packaging and transport. Each technique is examined in terms of its forensic reliability, statutory compliance, and alignment with international accreditation standards like ISO 17025 and the UK Forensic Science Regulator guidelines, with judicial precedents illustrating their probative value.
- The FOURTH CHAPTER analyses documentation protocols for toolmarks, covering scene documentation, laboratory documentation, structured forensic reporting, and digital archiving with metadata safeguards. This chapter emphasizes how proper documentation ensures reproducibility, peer review, and evidentiary integrity, aligning with BNSS Section 106 and BSA Sections 45 and 63.
- The FIFTH CHAPTER examines the legal provisions governing toolmark evidence, focusing on statutory mandates under BNSS and BSA, judicial precedents such as *State v. Ramesh Kumar* and *State v. Arunachalam*, and constitutional safeguards under Article 21. It highlights how lapses in the chain of custody, documentation, or preservation can compromise admissibility and fairness in criminal trials.
- Finally, the SIXTH CHAPTER presents the conclusion, synthesizing the findings of the study and offering suggestions for reforms. It emphasizes the need for standardized protocols, digital archiving, centralized databases, judicial awareness, and continuous professional development to strengthen the reliability of toolmark evidence and advance victim-centered justice in India.

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CHAPTER -2

2.1 Preservation Techniques of Toolmarks

2.1.1 high-resolution photography

High-resolution photography plays a foundational role in forensic documentation of toolmarks, offering a non-invasive and scientifically reliable method for preserving evidence at crime scenes[993]. It is often the first step in recording toolmark evidence, especially when the mark appears on delicate or immovable surfaces such as painted metal, glass, or wood, where physical casting might risk damaging the original trace. By capturing the mark in its untouched state, photography ensures that the physical characteristics are retained for further analysis without compromising the integrity of the evidence.

This process relies on specialized equipment, including macro lenses, forensic scales, and oblique lighting[994]. Macro lenses enable extreme close-up imaging, revealing minute striations and surface irregularities that are critical for forensic comparison. Oblique lighting, angled illumination from the side, casts shadows that highlight the three-dimensional contours of the mark, making it easier to differentiate between impression and striated features. Forensic scales are placed adjacent to the toolmark to provide accurate spatial reference, often incorporating both metric and imperial units along with color calibration bars to correct for lighting inconsistencies. Each photograph must also include evidence tags and case identifiers to maintain the chain of custody and prevent misattribution during legal proceedings.

Digital imaging offers several advantages over traditional film-based methods. It allows for immediate documentation, remote peer review, and seamless integration with forensic databases. Digital photographs can be enhanced, annotated, and archived without altering the original evidence. However, the reliability of photographic documentation depends heavily on technical consistency. Forensic photographers must ensure uniformity in camera angle, lighting conditions, resolution, and focus across all images. Any deviation can introduce bias or render the evidence inadmissible in court, as emphasized by Peterson and Sommers (2010)[995].

To preserve image integrity, photographs should be stored in lossless formats such as TIFF or RAW[996]. Compressed formats like JPEG can introduce artifacts that obscure fine details, potentially compromising forensic analysis. Additionally, metadata, including date, time, GPS coordinates, and camera settings, must be embedded and protected to support the authenticity and traceability of the evidence.

In the Indian legal context, high-resolution photographic documentation aligns with Section 106 of the Bharatiya Nagarik Suraksha Sanhita (BNSS), which emphasizes the scientific preservation of physical evidence[997]. It also supports expert testimony under Section 45 of the Bharatiya Sakshya Adhiniyam (BSA), where visual aids can substantiate forensic conclusions[998]. Thus, high-resolution photography is not merely a technical tool; it is a legal safeguard that ensures toolmark evidence is preserved, authenticated, and admissible, contributing meaningfully to the pursuit of justice.

2.1.2 Casting and molding

Casting and molding are indispensable techniques in forensic science for preserving three-dimensional toolmarks, especially when the evidence is found on surfaces that cannot be moved or are irregular, such as door frames, safes, concrete walls, or wooden panels. These methods allow forensic experts to create

[993] Saferstein, R. (2015). *Criminalistics: An Introduction to Forensic Science*. 12th ed. Pearson.
[994] James, S.H., Nordby, J.J., & Bell, S. (2014). *Forensic Science: An Introduction to Scientific and Investigative Techniques*. CRC Press
[995] Peterson, J., & Sommers, I. (2010). *Forensic Evidence and Criminal Justice: Toolmarks and Their Role in Investigations*. Journal of Forensic Sciences, 55(2), 345–356
[996] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[997] Bharatiya Nagarik Suraksha Sanhita, 2023, Section 106. Government of India Gazette Notification
[998] Bharatiya Sakshya Adhiniyam, 2023, Section 45. Government of India Gazette Notification

durable, high-fidelity replicas of toolmarks that can be examined, stored, and presented in court without disturbing the original surface[999]. This is particularly crucial in cases where the toolmark is the only physical link between the suspect and the crime scene.

Among the most widely used casting materials in forensic practice are silicone-based compounds like Mikrosil, AccuTrans, and Silmark[1000]. These compounds are preferred for their ability to capture intricate surface details, including microscopic striations and subtle contour variations. Their flexibility, dimensional stability, and low shrinkage make them ideal for forensic comparison under stereo or comparison microscopes, ensuring that even the finest features of the toolmark are preserved with precision.

The casting process begins with careful surface preparation. The tool marked area is cleaned to remove dust, moisture, or debris that could interfere with the replication. The silicone compound is then mixed and applied evenly over the mark using spatulas or syringes, depending on the surface geometry. Once the material cures, the cast is gently removed and labelled with essential case details such as date, location, and identifier codes. To prevent warping or contamination, the cast is sealed in rigid containers for safe transport and storage.

Best practices in forensic documentation require that casts be photographed both before and after removal. These photographs should include forensic scales and evidence tags to ensure traceability and maintain the chain of custody. This aligns with Section 106 of the Bharatiya Nagarik Suraksha Sanhita (BNSS), which mandates scientific preservation of physical evidence. Additionally, casts can be digitized using 3D laser profilometry, allowing for enhanced visualization in courtrooms and facilitating peer review among forensic experts[1001].

Casting is especially effective for impression toolmarks, where depth and contour are vital for matching the tool to the mark. It can also be applied to combination marks, provided the striations are deep enough to be captured. However, when dealing with fragile surfaces or shallow marks, alternative methods such as electrostatic lifting or photogrammetry may be more appropriate.

Legally, cast replicas are admissible under Section 45 of the Bharatiya Sakshya Adhiniyam, 2023, which recognizes expert opinion and scientifically preserved evidence. The importance of casting was notably affirmed in the case of *State v. Ramesh Kumar* (AIR 2024 SC 1189), where toolmark casts played a decisive role in linking the accused to a forced entry[1002]. Thus, casting is not just a technical procedure; it is a forensic and legal safeguard that ensures toolmark evidence remains intact, traceable, and admissible throughout the judicial process.

2.1.3 Electrostatic and Gel Lifting

Electrostatic Lifting

Electrostatic lifting involves the use of an electrostatic dust lifter, a device that applies a high-voltage charge to a lifting film placed over the toolmark[1003]. The charge attracts dust and fine particles from the surface, transferring the latent mark onto the film. This method is non-destructive and ideal for preserving trace-level impressions that would otherwise be lost during handling or environmental exposure.

The lifted image is then photographed under oblique lighting and stored in protective sleeves[1004]. Electrostatic lifts are particularly effective for impression toolmarks left in dust or powder-coated surfaces, such as those found on window sills, painted doors, or vehicle

[999] Jackson, A.R.W., & Jackson, J.M. (2011). *Forensic Science*. Pearson Education.
[1000] Bodziak, W.J. (2017). *Footwear Impression Evidence: Detection, Recovery, and Examination*. CRC Press.
[1001] De Kinder, J., & Bonfanti, M. (2005). "3D Imaging in Forensic Toolmark Analysis." *Forensic Science International*, 150(1), 27–36
[1002] *State v. Ramesh Kumar*, AIR 2024 SC 1189. Supreme Court of India.
[1003] Grieve, M.C. (2001). "Electrostatic Dust Print Lifting: Principles and Applications." *Science & Justice*, 41(3), 193–200
[1004] James, S.H., Nordby, J.J., & Bell, S. (2014). *Forensic Science: An Introduction to Scientific and Investigative Techniques*. CRC Press

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exteriors. However, the technique requires controlled environmental conditions and immediate processing to prevent loss of detail due to static discharge or humidity.

Gel Lifting

Gel lifting uses transparent or opaque gelatine-based sheets that conform to the surface and lift residues, including toolmark impressions, without damaging the substrate[1005]. These sheets are pressed gently onto the surface and then peeled away, capturing the mark along with any particulate evidence. Gel lifters are useful for non-porous surfaces and can preserve both striation patterns and surface texture, making them suitable for forensic comparison.

The lifted toolmark is then scanned or photographed with forensic scales and stored in archival conditions[1006]. Gel lifting is often used in conjunction with chemical enhancement techniques, such as cyanoacrylate fuming or powder development, to improve visibility before lifting[1007].

2.1.4 Packaging and Transport

Packaging Protocols

Preserved tool-marked items must be placed in **rigid, shock-resistant containers** with internal padding to prevent any contact between the tool mark and the packaging surface[1008]. For example, silicone casts are stored in hard plastic boxes with foam inserts, while metal or wooden substrates bearing toolmarks are immobilized using clamps or custom-cut compartments. Each package must be labelled with:

- Case number and evidence ID
- Date and time of collection
- Collector's name and designation
- Description of contents and preservation method

Additionally, **tamper-evident seals**, **barcoded evidence tags**, and **photographic documentation** of the packaged item are essential to maintain evidentiary continuity[1009]. These measures align with the forensic accountability required under **Section 45 of the Bharatiya Sakshya Adhiniyam (BSA), 2023**, which governs expert testimony and admissibility of physical evidence.

Transport Considerations

During transport, toolmarked items must be shielded from **vibration, temperature fluctuations, and environmental contaminants**. Forensic transport vehicles should be equipped with climate control systems and secure evidence lockers. In high-profile or multi-jurisdictional cases, **GPS tracking**, **digital chain-of-custody logs**, and **inter-agency transfer forms** are employed to ensure transparency and traceability[1010].

Evidence must be transported **separately from biological or chemical samples** to prevent cross-contamination[1011]. In cases involving multiple items, each must be individually packaged and catalogued to avoid confusion or evidentiary dilution. Upon arrival at the forensic laboratory or courtroom, the condition of the package is re-verified, and any discrepancies are documented immediately.

2.2 Challenges in the Preservation of Toolmark Evidence

2.2.1 Surface Fragility and Substrate Sensitivity

Toolmarks often occur on delicate surfaces such as painted metal, wood, drywall, or glass, which are inherently vulnerable to distortion[1012]. During collection or transport, these substrates may suffer smudging, abrasion, or

[1005] Bodziak, W.J. (2017). *Footwear Impression Evidence: Detection, Recovery, and Examination*. CRC Press.
[1006] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[1007] Champod, C., Lennard, C., Margot, P., & Stoilovic, M. (2016). *Fingerprints and Other Ridge Skin Impressions*. CRC Press.
[1008] Jackson, A.R.W., & Jackson, J.M. (2011). *Forensic Science*. Pearson Education.
[1009] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[1010] Grieve, M.C. (2001). "Chain of Custody and Evidence Transport in Forensic Practice." *Science & Justice*, 41(4), 241–248
[1011] Saferstein, R. (2015). *Criminalistics: An Introduction to Forensic Science*. 12th ed. Pearson.
[1012] Saferstein, R. (2015). *Criminalistics: An Introduction to Forensic Science*. 12th ed. Pearson.

deformation—especially when casting compounds are applied without compatibility testing. Inadequate handling protocols or lack of scene-specific training can result in the irreversible loss of critical striation patterns, undermining the evidentiary value of the mark[1013].

2.2.2 Environmental Degradation

Toolmarks are highly susceptible to environmental deterioration. Exposure to humidity, temperature fluctuations, and ultraviolet light can cause corrosion, fading, or substrate warping[1014]. Biological contaminants such as dust, blood, or skin oils may obscure fine toolmark details or interfere with casting and lifting techniques. In field conditions where climate control is absent, the window for effective preservation narrows significantly, necessitating rapid and precise documentation.[1015]

2.2.3 Inadequate Photography and Lighting

High-resolution photography is essential for capturing the microstructure of toolmarks, yet it is frequently compromised by poor technique[1016]. Improper lighting angles, absence of oblique illumination, and failure to use macro lenses can obscure depth and striation features. Additionally, photographs lacking forensic scales or evidence tags lose spatial and contextual relevance. Such deficiencies render the images unsuitable for comparative analysis and may lead to exclusion under Section 45 of the BSA due to a lack of reproducibility.

2.2.4 Packaging and Transport Errors

Improper packaging remains a critical point of failure in toolmark preservation[1017]. When tool-marked surfaces come into contact with packaging materials, abrasion or compression may occur, distorting the evidence. Silicone casts are particularly vulnerable to warping under temperature or pressure changes. Furthermore, missing or incomplete chain-of-custody documentation violates Section 106 of the BNSS, jeopardizing the traceability and admissibility of the evidence. Judicial precedents such as *State v. Arunachalam* (2024) have highlighted the consequences of such procedural lapses.

2.2.5 Material Compatibility and Casting Failures

Casting compounds, while effective, are not universally compatible with all substrates[1018]. Painted or porous surfaces may absorb or chemically react with the compound, altering the toolmark's morphology. Errors in curing time, uneven application, or the reuse of contaminated tools can result in distorted impressions or introduce foreign striations. These failures compromise the integrity of the cast and hinder individualization, especially when the original mark is no longer accessible.

2.2.6 Documentation Gaps and Metadata Omissions

Digital records must be accompanied by comprehensive metadata, including timestamps, examiner credentials, camera settings, and preservation methods[1019]. The absence of such data undermines authenticity under Section 63 of the BSA and weakens the evidentiary chain[1020]. Additionally, missing scene sketches, environmental logs, or test mark protocols reduce the interpretive value of the evidence and limit its utility in forensic reconstruction and expert testimony.

2.2.7 Lack of Standardization and Training

India currently lacks a centralized toolmark database and national accreditation system for

[1013] James, S.H., Nordby, J.J., & Bell, S. (2014). *Forensic Science: An Introduction to Scientific and Investigative Techniques*. CRC Press
[1014] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[1015] Jackson, A.R.W., & Jackson, J.M. (2011). *Forensic Science*. Pearson Education.
[1016] Champod, C., Lennard, C., Margot, P., & Stoilovic, M. (2016). *Fingerprints and Other Ridge Skin Impressions*. CRC Press.
[1017] Bodziak, W.J. (2017). *Footwear Impression Evidence: Detection, Recovery, and Examination*. CRC Press.
[1018] De Kinder, J., & Bonfanti, M. (2005). "3D Imaging in Forensic Toolmark Analysis." *Forensic Science International*, 150(1), 27–36
[1019] ISO/IEC 17025:2017. *General Requirements for the Competence of Testing and Calibration Laboratories*. International Organization for Standardization.
[1020] Bharatiya Sakshya Adhiniyam, 2023, Section 63. Government of India Gazette Notification

toolmark analysis[1021]. This results in inconsistent preservation practices across jurisdictions, limited peer review, and insufficient training in advanced techniques such as 3D profilometry, electrostatic lifting, and digital archiving. Without standardized protocols and continuous professional development, forensic conclusions may be challenged on grounds of scientific validity and procedural fairness, raising constitutional concerns under Article 21[1022].

CHAPTER-3

3.1 Documentation Protocols for Toolmarks

3.1.1 Scene Documentation

Scene documentation is the foundational step in establishing the forensic and legal relevance of toolmark evidence. It involves the systematic recording of toolmarks in their original context—before any preservation or removal ensuring that the spatial, environmental, and situational details are captured with precision[1023]. This process is critical not only for forensic reconstruction but also for maintaining the integrity of the **chain of custody**, as mandated under **Section 106 of the Bharatiya Nagarik Suraksha Sanhita (BNSS), 2023**.

Toolmarks may be found on a variety of surfaces—door frames, window sills, safes, locks, walls, or even human tissue in cases of assault[1024]. Their location, orientation, and proximity to other evidence (e.g., fingerprints, bloodstains, broken objects) must be documented through a combination of **photography**, **sketching**, **video recording**, and **written notes**. Investigators use **evidence markers**, **forensic scales**, and **reference grids** to ensure that each toolmark is spatially contextualized within the crime scene[1025].

High-resolution photographs are taken using **macro lenses** and **oblique lighting** to highlight striations and depth. These images must include forensic rulers and case identifiers to support later comparison and courtroom presentation. In complex scenes, **3D photogrammetry** or **laser scanning** may be employed to digitally reconstruct the environment and preserve the toolmark's spatial relationship to other evidence[1026].

Sketches complement photographs by providing a schematic overview of the scene. They include measurements, compass orientation, and annotations describing the toolmark's appearance, suspected tool type, and any visible damage[1027]. These sketches are especially useful in cases where digital imaging is restricted due to lighting, access, or legal constraints.

Scene documentation also involves **environmental recording,** noting temperature, humidity, lighting conditions, and surface contamination, which may affect the preservation and interpretation of toolmarks[1028]. For example, toolmarks on painted metal may degrade under high humidity, while dust accumulation may obscure striations on glass surfaces.

All documentation must be timestamped, signed, and stored in secure digital or physical formats[1029]. Investigators are required to maintain **field logs**, **evidence collection forms**, and **scene narratives**, which together form the basis of the forensic report. These records are admissible under **Section 45 of the Bharatiya Sakshya Adhiniyam, 2023**, which governs expert testimony and evidentiary authentication.

In judicial proceedings, scene documentation serves as the **primary evidentiary link** between

[1021] AFTE (Association of Firearm and Toolmark Examiners). (2023). *AFTE Glossary and Standard Protocols for Toolmark Examination*. AFTE Journal, 55(3), 210–225
[1022] Singh, R. (2024). *Constitutional Justice and Forensic Evidence in India*. Indian Law Journal, 12(1), 55–72
[1023] Saferstein, R. (2015). *Criminalistics: An Introduction to Forensic Science*. 12th ed. Pearson.
[1024] James, S.H., Nordby, J.J., & Bell, S. (2014). *Forensic Science: An Introduction to Scientific and Investigative Techniques*. CRC Press
[1025] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[1026] De Kinder, J., & Bonfanti, M. (2005). "3D Imaging in Forensic Toolmark Analysis." *Forensic Science International*, 150(1), 27–36
[1027] Jackson, A.R.W., & Jackson, J.M. (2011). *Forensic Science*. Pearson Education.
[1028] Champod, C., Lennard, C., Margot, P., & Stoilovic, M. (2016). *Fingerprints and Other Ridge Skin Impressions*. CRC Press.
[1029] ISO/IEC 17025:2017. *General Requirements for the Competence of Testing and Calibration Laboratories*. International Organization for Standardization.

the physical toolmark and its forensic interpretation. Courts rely on this documentation to assess the credibility of expert analysis, the reliability of preservation methods, and the procedural fairness of the investigation. As such, scene documentation is not merely a technical exercise, it is a **constitutional safeguard** that upholds the right to a fair trial under **Article 21 of the Indian Constitution**.

3.1.2 **Laboratory Documentation**

Once toolmark evidence is preserved and transported to the forensic laboratory, it undergoes a series of analytical procedures aimed at comparison, classification, and individualization. Laboratory documentation is the process of recording these procedures in a scientifically valid and legally admissible format. It bridges the gap between raw physical evidence and expert testimony, ensuring that every step of the forensic analysis is traceable, reproducible, and defensible under judicial scrutiny[1030].

The core of laboratory documentation lies in **comparative analysis**, where the suspected tool is tested against the preserved mark. Forensic examiners create **test marks** by applying the tool to a similar substrate under controlled conditions, replicating the angle, pressure, and motion believed to have occurred during the crime. These test marks are then examined alongside the original using **comparison microscopes**, which allow simultaneous viewing of both marks at high magnification. The goal is to identify **class characteristics** (e.g., width, shape, manufacturing patterns) and **individual characteristics** (e.g., wear, nicks, burrs) that can link the tool to the mark with a high degree of certainty[1031].

Advanced laboratories may employ **3D laser profilometry**, **digital overlay software**, and **superimposition techniques** to enhance the precision of comparison[1032]. These technologies generate high-fidelity digital models of the toolmark, enabling quantitative analysis of depth, spacing, and striation patterns. The process is governed by international standards such as the **AFTE Theory of Identification**, which requires that any match be based on sufficient agreement in individual characteristics and be reproducible across multiple trials (AFTE, 2023)[1033].

All observations, measurements, and analytical steps are recorded in **structured laboratory logs**, which include:

- Equipment used and calibration status
- Environmental conditions during analysis
- Photographic documentation of each stage
- Annotated comparison images
- Examiner's notes and preliminary conclusions

These logs form the basis of the **forensic report**, which is submitted to the investigating agency and may be presented in court. Under **Section 45 of the Bharatiya Sakshya Adhiniyam (BSA), 2023**, such reports are admissible as expert evidence, provided they are prepared by qualified personnel using validated methods.

Laboratory documentation also includes **digital archiving**, where images, scans, and metadata are stored in secure forensic databases. Although India currently lacks a centralized toolmark repository, laboratories are encouraged to maintain internal databases for cross-case comparison and peer review. International models such as the **FBI's NIBIN** and Germany's automated toolmark systems

[1030] Jackson, A.R.W., & Jackson, J.M. (2011). *Forensic Science*. Pearson Education.
[1031] Saferstein, R. (2015). *Criminalistics: An Introduction to Forensic Science*. 12th ed. Pearson.
[1032] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[1033] AFTE (Association of Firearm and Toolmark Examiners). (2023). *AFTE Glossary and Standard Protocols for Toolmark Examination*. AFTE Journal, 55(3), 210–225

offer scalable frameworks that India may adopt in future reforms[1034].

In sum, laboratory documentation transforms preserved toolmarks into scientifically validated evidence. It ensures that forensic conclusions are not only accurate but also legally robust, supporting the principles of procedural fairness and evidentiary integrity under **Article 21 of the Indian Constitution**.

3.1.3 **Structured Forensic Reporting**

Structured forensic reporting is the formal culmination of the toolmark analysis process. It transforms raw observations, preserved evidence, and laboratory comparisons into a legally admissible document that supports expert testimony and judicial decision-making. Under **Section 45 of the Bharatiya Sakshya Adhiniyam (BSA), 2023**, forensic reports prepared by qualified experts using validated scientific methods are recognized as admissible evidence, provided they are clear, objective, and methodologically sound[1035].

A standard toolmark report includes several key components:

- **Identification and Classification**: The report begins with a description of the toolmark type whether it is an impression, striation, or combination mark. This classification is based on scene documentation and laboratory analysis, and it determines the analytical approach used[1036].
- **Preservation Methodology**: The report details how the toolmark was preserved, including the use of high-resolution photography, silicone casting, electrostatic lifting, or gel lifting. It also notes the packaging and transport protocols followed to maintain the chain of custody, as required under **Section 106 of the BNSS[1037]**.
- **Analytical Findings**: This section presents the results of the comparative analysis. It includes annotated photographs, microscope images, 3D scans, and measurement data. The examiner describes the class and individual characteristics observed, and whether they are consistent with the suspected tool. If test marks were created, their methodology and results are documented[1038].
- **Expert Opinion**: Based on the findings, the examiner provides a conclusion regarding the match probability. This may be categorized as:
    - **Individualization**: The toolmark matches the suspected tool to the exclusion of all others.
    - **Exclusion**: The toolmark does not match the suspected tool.
    - **Inconclusive**: The evidence is insufficient to reach a definitive conclusion[1039].
- **Limitations and Caveats**: Ethical forensic reporting includes a statement of limitations, such as environmental degradation, partial marks, or lack of comparative standards. This transparency enhances the credibility of the report and protects against overstatement[1040].
- **Certification and Accreditation**: The report concludes with the examiner's credentials, laboratory accreditation status (e.g., ISO 17025), and a declaration

[1034] Bonfanti, M., & De Kinder, J. (2000). "The Influence of Surface Conditions on Toolmark Comparisons." *Forensic Science International*, 109(1), 1–16
[1035] Bharatiya Sakshya Adhiniyam, 2023, Section 45. Government of India Gazette Notification
[1036] Saferstein, R. (2015). *Criminalistics: An Introduction to Forensic Science*. 12th ed. Pearson.
[1037] Bharatiya Nagarik Suraksha Sanhita, 2023, Section 106. Government of India Gazette Notification
[1038] James, S.H., Nordby, J.J., & Bell, S. (2014). *Forensic Science: An Introduction to Scientific and Investigative Techniques*. CRC Press
[1039] Peterson, J., & Sommers, I. (2010). *Forensic Evidence and Criminal Justice: Toolmarks and Their Role in Investigations*. Journal of Forensic Sciences, 55(2), 345–356
[1040] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.

of compliance with national and international forensic standards[1041].

Structured forensic reports are not only technical documents; they are **judicial instruments**. They must be formatted to meet courtroom expectations, using clear language, logical structure, and visual aids that can be understood by judges, lawyers, and juries. In high-profile cases, reports may be supplemented with **expert affidavits**, **courtroom exhibits**, and **digital presentations** to facilitate comprehension[1042].

In the Indian context, the reliability of toolmark reports has been affirmed in cases such as *State v. Ramesh Kumar* (AIR 2024 SC 1189), where the Supreme Court accepted a toolmark report as decisive evidence linking the accused to a forced entry[1043]. The judgment emphasized the importance of structured reporting, expert qualification, and adherence to scientific protocols.

Thus, structured forensic reporting is the bridge between forensic science and legal adjudication. It ensures that toolmark evidence is not only scientifically valid but also procedurally and constitutionally sound under **Article 21 of the Indian Constitution**[1044].

3.1.4 Digital Archiving and Metadata

Digital archiving has emerged as a cornerstone of modern forensic practice, offering scalable, secure, and searchable platforms for storing toolmark evidence. It ensures long-term preservation, facilitates cross-case comparison, and enhances courtroom presentation. In the context of toolmark analysis, digital archiving involves the systematic storage of high-resolution images, 3D scans, comparison overlays, and metadata in forensic databases that comply with evidentiary standards under **Section 63 of the Bharatiya Sakshya Adhiniyam, 2023**[1045].

Toolmark images captured through macro photography, comparison microscopy, or laser profilometry are stored in **lossless formats** such as TIFF or RAW to preserve detail and prevent compression artifacts. Each image is tagged with **metadata**, including:

- Case number and evidence ID
- Date and time of capture
- Camera settings and lighting conditions
- Examiner's name and laboratory credentials
- Preservation method (e.g., casting, lifting, photography)

This metadata not only supports authenticity but also enables **automated retrieval**, **audit trails**, and **chain-of-custody verification**, aligning with the procedural safeguards mandated under **Section 106 of the BNSS, 2023**.

international models offer viable templates:

- The **FBI's National Integrated Ballistic Information Network (NIBIN)** stores firearm-related toolmarks for cross-case matching[1046].
- Germany's **automated toolmark systems** integrate 3D imaging and AI-based pattern recognition for rapid identification[1047].
- The **UK Forensic Science Regulator** mandates digital traceability and ISO 17025 compliance for all forensic archives[1048].

In courtroom settings, digital archives allow for **visual presentation of evidence**. Judges and juries can view annotated images, comparison

[1041] ISO/IEC 17025:2017. *General Requirements for the Competence of Testing and Calibration Laboratories*. International Organization for Standardization
[1042] Jackson, A.R.W., & Jackson, J.M. (2011). *Forensic Science*. Pearson Education.
[1043] *State v. Ramesh Kumar*, AIR 2024 SC 1189. Supreme Court of India
[1044] Singh, R. (2024). *Constitutional Justice and Forensic Evidence in India*. Indian Law Journal, 12(1), 55–72
[1045] Bharatiya Sakshya Adhiniyam, 2023, Section 63. Government of India Gazette Notification
[1046] FBI. (2023). *National Integrated Ballistic Information Network (NIBIN)*. Federal Bureau of Investigation.
[1047] Bonfanti, M., & De Kinder, J. (2000). "The Influence of Surface Conditions on Toolmark Comparisons." *Forensic Science International*, 109(1), 1–16
[1048] UK Forensic Science Regulator. (2024). *Codes of Practice and Conduct for Forensic Science Providers.*

overlays, and 3D reconstructions that clarify the forensic findings[1049]. This enhances transparency and supports judicial comprehension, especially in cases involving complex striation patterns or partial toolmarks.

3.2. Challenges in the Documentation of Toolmark Evidence

3.2.1 Scene-Level Documentation Gaps

At the crime scene, toolmarks must be recorded with precision and context. Yet, investigators often face limitations in time, lighting, and access, leading to incomplete or inconsistent documentation. The absence of forensic scales, evidence tags, or oblique lighting in photographs can obscure striation patterns and depth features[1050]. Sketches may lack spatial orientation, measurements, or annotations, weakening their utility in reconstruction. Environmental conditions—such as humidity, substrate contamination, or poor visibility—may not be recorded, despite their impact on preservation. These gaps undermine the chain of custody mandated under Section 106 of BNSS and reduce the interpretive value of the evidence in court.

3.2.2 Laboratory Documentation Deficiencies

In forensic laboratories, toolmark analysis must be meticulously recorded to ensure reproducibility and expert credibility[1051]. However, many labs lack standardized protocols for documenting test mark creation, comparison procedures, and instrument calibration. Without detailed logs, peer review becomes difficult and expert conclusions may be challenged for lack of transparency. The omission of comparative overlays, 3D scans, or annotated images limits the report's evidentiary strength. In high-profile cases, failure to document analytical steps can result in judicial exclusion under Section 45 of the BSA, which requires scientifically validated expert testimony.

3.2.3Structured Reporting Errors

Forensic reports must be clear, objective, and legally formatted. Yet, challenges persist in report writing due to ambiguous terminology, missing classifications, and a lack of supporting visuals. Reports that fail to specify the type of toolmark (impression, striation, combination) or omit preservation methods risk misinterpretation. Expert opinions may be stated without a statistical basis or caveats, leading to overstatement or evidentiary dilution. Courts increasingly demand structured, peer-reviewed reports that meet judicial expectations—especially in cases where toolmark evidence is central to conviction[1052].

3.2.4 Digital Archiving and Metadata Limitations

Digital documentation offers scalability and traceability, but it is vulnerable to metadata omissions and storage risks[1053]. Images without timestamps, examiner credentials, or camera settings may be deemed inauthentic under Section 63 of the BSA. Use of lossy formats like JPEG can degrade image quality, obscuring fine details critical for comparison. Without encryption, access logs, and backup protocols, digital archives are susceptible to tampering or data loss[1054]. India's lack of a centralized toolmark repository further limits cross-case comparison and forensic standardization[1055].

3.2.5 Procedural and Training Gaps

Documentation quality is often compromised by non-standardized formats and insufficient training. Investigators may lack exposure to advanced tools such as 3D photogrammetry, digital overlays, or automated comparison systems. Overreliance on manual logs without

[1049] De Kinder, J., & Bonfanti, M. (2005). "3D Imaging in Forensic Toolmark Analysis." *Forensic Science International*, 150(1), 27–36
[1050] Peterson, J., & Sommers, I. (2010). *Forensic Evidence and Criminal Justice: Toolmarks and Their Role in Investigations*. Journal of Forensic Sciences, 55(2), 345–356
[1051] Houck, M.M., & Siegel, J.A. (2018). *Fundamentals of Forensic Science*. 4th ed. Academic Press.
[1052] Singh, R. (2024). *Constitutional Justice and Forensic Evidence in India*. Indian Law Journal, 12(1), 55–72
[1053]Champod, C., Lennard, C., Margot, P., & Stoilovic, M. (2016). *Fingerprints and Other Ridge Skin Impressions*. CRC Press.
[1054] ISO/IEC 17025:2017. *General Requirements for the Competence of Testing and Calibration Laboratories*. International Organization
[1055] FBI. (2023). *National Integrated Ballistic Information Network (NIBIN)*. Federal Bureau of Investigation.

digital backups increases the risk of error and misinterpretation. These gaps highlight the need for national documentation standards, ISO accreditation, and continuous professional development to ensure that toolmark evidence withstands both scientific and judicial scrutiny[1056].

CHAPTER-4

4.1 Legal Provisions Governing the Preservation and Documentation of Toolmark Evidence in India

4.1.1 Section 106 of BNSS, 2023 – Chain of Custody and Scientific Handling

This provision mandates that all physical evidence collected during an investigation must be handled using scientific methods and documented with an unbroken chain of custody. For toolmark evidence, this includes:

- Proper packaging and labelling of tool-marked items.
- Scene-level documentation (photographs, sketches, environmental notes).
- Laboratory logs detailing preservation and analysis. Any lapse in these procedures may render the evidence inadmissible or legally challengeable or a procedural irregularity.

4.1.2 Section 45 of BSA, 2023 – Admissibility of Expert Opinion

Toolmark analysis falls under expert evidence. Section 45 recognizes the admissibility of opinions given by qualified forensic experts on matters requiring specialized knowledge. For toolmark reports to be admissible:

- The expert must be certified and the method scientifically validated.
- The report must be structured, objective, and reproducible.
- Visual documentation (e.g., annotated images, comparison overlays) must support the opinion.

4.1.3 Section 63 of BSA, 2023 – Admissibility of Electronic and Digital Records

Digital documentation of toolmarks such as high-resolution images, 3D scans, and metadata is admissible under Section 63, provided it meets authenticity and integrity standards. This includes:

- Metadata (timestamps, examiner credentials, camera settings).
- Secure storage (encryption, access logs).
- Traceability and audit trails. Failure to maintain digital integrity may lead to exclusion or evidentiary dilution.

4.1.4 Section 204 of IPC – Tampering or Destruction of Evidence

This provision criminalizes the destruction, concealment, or alteration of any document or electronic record intended for use as evidence. In the context of toolmarks:

- Mishandling or intentional distortion of casts, photographs, or digital files may attract penal consequences.
- Investigators and forensic personnel are legally obligated to preserve evidence in its original form.

4.1.5 Article 21 of the Constitution – Right to Fair Trial and Procedural Safeguards

Preservation and documentation failures can violate the accused's right to a fair trial under Article 21. Courts have held that forensic evidence must be collected and presented in a manner that ensures procedural fairness, transparency, and scientific reliability.

CHAPTER-5

5.1 Findings and Suggestions

Toolmark evidence, though recognized under the Bharatiya Nagarik Suraksha Sanhita (BNSS), 2023, and the Bharatiya Sakshya Adhiniyam

[1056] UK Forensic Science Regulator. (2024). *Codes of Practice and Conduct for Forensic Science Providers.*

(BSA), 2023, faces persistent challenges in forensic practice. Section 106 of BNSS mandates scientific preservation and chain of custody, while Section 45 of BSA permits expert testimony based on validated methods. Yet infrastructural and procedural gaps undermine reliability. Toolmarks, impressions, striated, and combination carry distinct forensic value, but a lack of standardized identification protocols limits consistent application. Preservation techniques such as high-resolution photography, silicone casting, and electrostatic lifting are validated, but fragile substrates, environmental degradation, and poor handling compromise evidence. Documentation remains inconsistent, with scene records often missing forensic scales or lighting, and laboratory reports lacking overlays or 3D scans. Judicial precedents affirm probative value when properly preserved (State v. Ramesh Kumar, 2024) but highlight exclusion risks from custody lapses (State v. Arunachalam, 2024).

Reforms are essential: national standardized protocols aligned with AFTE, ISO 17025, and UK guidelines; mandatory digital archiving with secure metadata; creation of a centralized toolmark database modelled on NIBIN; judicial training on forensic value and constitutional safeguards; laboratory upgrades with advanced equipment and accreditation; and continuous professional development for investigators. These measures will enhance reliability, reproducibility, and fairness in criminal trials.

5.2 Conclusion

The meticulous preservation and documentation of toolmarks are foundational to forensic investigations, particularly in cases involving burglary, assault, or homicide. By employing a combination of photographic techniques, casting methods, and microscopic comparisons, forensic experts ensure that toolmarks are accurately recorded and analysed. These methods not only help establish links between tools and crime scenes but also uphold the evidentiary integrity required for judicial scrutiny. As forensic science advances, digital imaging and 3D scanning are enhancing the precision and reproducibility of toolmark analysis, reinforcing its role as a critical component of modern criminal justice.