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"EXAMINATION AND MATCHING OF TOOLMARK EVIDENCE: A STUDY ON EVIDENTIARY RELIABILITY AND ETHICAL RESPONSIBILITY"

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ABSTRACT:

Toolmark evidence occupies a distinctive place in forensic science because of its ability to link a particular tool to a criminal act through unique impressions or striations. The reliability of such evidence, however, depends on the examination and matching of the toolmark evidence, which forms a critical component in the process of criminal investigation and adjudication. The scientific reliability, interpretative accuracy, and ethical conduct of forensic experts in this domain have come under judicial scrutiny. This study seeks to examine the scientific processes employed in identifying and comparing toolmarks while also exploring how variations in methodology, human subjectivity, and lack of standardized protocols may affect the accuracy of forensic conclusions and their admissibility in courts. This paper also studies traditional and advanced forensic methodologies including stereomicroscopy, comparison microscopy, scanning electron microscopy, and emerging digital and three-dimensional imaging techniques. It highlights the significance of class, subclass, and individual characteristics in the process of matching, while also identifying challenges such as tool wear, environmental influences, and examiner subjectivity. By addressing issues of reproducibility, error rates, and limitations in existing protocols, the study evaluates the extent to which toolmark evidence can be considered scientifically valid and legally reliable. Through doctrinal analysis on the legal note focusing on the admissibility of toolmark evidence under the Bharatiya Sakshya Adhiniyam, 2023, supported by forensic case studies, it evaluates whether existing legal frameworks adequately address the ethical challenges, professional accountability, and potential biases in forensic reporting. The study concludes that while toolmark evidence is an indispensable investigative aid, its legal credibility requires enhanced standardization, technological integration, and expert accountability. Strengthening forensic methodologies and aligning them with robust judicial scrutiny will not only improve the evidentiary value of toolmark analysis but also safeguard the fairness of criminal trials.

KEYWORDS: Toolmark Evidence, Forensic Methodologies, Evidentiary value, Judicial Scrutiny, Expert Accountability.

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION:

Forensic science has emerged as a cornerstone of the modern criminal justice system, offering scientific objectivity in the investigation and adjudication of criminal cases. Among the various branches of forensic science, toolmark evidence occupies a vital position due to its ability to link an accused person, a weapon, or an instrument directly to the scene of crime. Toolmarks, being the impressions or striations left by a hard object upon another surface, often serve as silent witnesses that narrate the

manner in which an offence was committed[1200]. Their accurate examination and matching are vital for establishing strong evidentiary connections that support the prosecution's case. India's new criminal laws further emphasize scientific investigation and the use of forensic experts. Under Section 39 of the BSA, 2023, investigating officers must consult forensic experts in serious offences to ensure accuracy and transparency.

Despite these advancements, questions persist regarding the **evidentiary reliability** and **ethical responsibility** of forensic experts engaged in toolmark examination. The subjective interpretation of microscopic patterns, inconsistencies in comparison methods, and lack of standardized protocols across forensic laboratories often raise doubts about the objectivity and reproducibility of findings. Errors in examination or subjective interpretation can result in miscarriage of justice, as seen in several wrongful conviction cases globally. Hence, the responsibility of forensic experts extends beyond scientific accuracy to encompass ethical accountability. The present study seeks to analyze, in depth, the examination and matching of toolmark evidence within the framework of the new criminal laws, focusing on two key aspects: (i) the scientific and evidentiary reliability of such evidence, and (ii) the ethical responsibilities of forensic experts in its handling, interpretation, and presentation before courts. The aim is to ensure that toolmark evidence, when produced in courts, stands as reliable, transparent, and ethically sound proof, upholding the fundamental principles of justice enshrined in the Constitution of India and the procedural mandates of the BNSS and BSA.

1.2 AIMS AND OBJECTIVES:

- To examine the concept, nature, and forensic importance of toolmark evidence in criminal investigation and prosecution.
- To analyze the procedures and techniques used in the examination and matching of toolmarks, including comparison microscopy, 3D imaging, and digital databases.
- To evaluate the evidentiary reliability and probative value of toolmark evidence in light of judicial interpretations and scientific validation standards.
- To identify ethical challenges and responsibilities of forensic experts in the process of examination, interpretation, and courtroom presentation of toolmark evidence.
- To suggest reforms and best practices for strengthening the reliability, transparency, and ethical accountability in toolmark examination and reporting.

- **REVIEW OF LITERATURE:**
- **Nichols, R. (2007)[1201]:** The article examines the physical basis for toolmark individuality and the reproducibility of microscopic striation patterns, supporting the concept that no two tools leave identical marks. It highlights the need for methodological transparency and training themes directly relevant to evidentiary reliability and ethical responsibility in forensic toolmark analysis.
- **Baldwin, D. P (2014)[1202]:** The study's quantitative assessment of error directly supports the argument that evidentiary reliability depends on objective validation and standardization of forensic methodologies. It also stresses ethical reporting of uncertainty, which is crucial for expert testimony integrity under the Indian Evidence Act.

[1200] Monson, K. L., et al., "Accuracy of Comparison Decisions by Forensic Firearms Examiners," *Journal of Forensic Sciences*, Vol. 59, No. 5, 2014, pp. 1221–1231; De Kinder, J., & Bonfanti, M., "Automated Comparison of Striated Toolmarks: The BulletTRAX-3D System," *Forensic Science International*, Vol. 156, No. 2–3, 2005, pp. 163–172

[1201] Nichols, R. (2007)[1201]. "The Scientific Foundations of Firearms and Toolmark Identification: A Response to Recent Challenges." *Journal of Forensic Sciences*, Vol. 52, No. 3, pp. 586–594

[1202] Baldwin, D. P., Bajic, S., Morris, M. D., & Zamzow, D. S. (2014)[1202] "A Study of False-Positive and False-Negative Error Rates in Cartridge Case Comparisons." *Journal of Forensic Sciences*, Vol. 59, No. 5, pp. 1221–1231

- **De Kinder, J., & Bonfanti, M. (2005)[1203]:** The paper discusses the technological advancement of three-dimensional imaging systems in toolmark examination. Their findings emphasize the transition from subjective visual comparison to automated digital evaluation, improving reproducibility and courtroom defensibility. This work provides a strong scientific foundation for incorporating modern 3D imaging and database-assisted comparison tools into forensic practice.
- **Mnookin, J. L. (2008)[1204]:** She critically evaluates the intersection between forensic identification science and the legal standards governing admissibility of expert evidence. She argues that traditional forensic techniques such as toolmark and fingerprint analysis often lack rigorous statistical validation, which undermines their evidentiary reliability under judicial scrutiny. The paper highlights ethical concerns arising from overstatement of certainty by experts in court.
- **Singh, R., & Sharma, P. (2022)[1205]:** It explored the ethical dimensions of forensic science practice in India, focusing on the duty of impartiality, transparency, and responsibility in expert testimony. The paper notes that while forensic evidence such as toolmark impressions strengthens investigative accuracy, ethical lapses such as bias, selective reporting, or lack of competence can compromise justice.

1.3 STATEMENT OF THE PROBLEM:

Despite the growing use of forensic science in criminal investigations, the reliability and ethical accountability of toolmark evidence remain questionable. Toolmark examination often suffers from subjective interpretation, lack of standardized methods, and inadequate validation across forensic labs in India. Although the BNSS, 2023 and BSA, 2023 emphasize scientific investigation and expert evidence, challenges persist in ensuring accuracy, transparency, and ethical conduct among forensic experts. Judicial rulings like underscore the need for credible and corroborated expert opinions, yet inconsistencies continue. The study thus addresses whether examination and matching of toolmark evidence in India meets the standards of scientific reliability and ethical responsibility required under the new criminal law.

1.4 RESEARCH METHODOLOGY:

This study adopts a doctrinal-cum-analytical research methodology, combining qualitative analysis of legal provisions, judicial decisions, and forensic literature with a review of modern scientific techniques in toolmark examination. Primary sources include the BNS, BNSS, and BSA (2023), the Indian Evidence Act, and landmark judgments, while secondary sources comprise research journals, books, and reports on forensic practices and automated databases (NIBIN, IBIS, Evofinder). Data collection involves document and literature analysis, complemented by comparative and thematic evaluation to assess scientific reliability, ethical responsibilities, and legal admissibility of toolmark evidence.

1.5 SCOPE AND LIMITATION:

The study focuses on the scientific examination, matching, and ethical evaluation of toolmark evidence in India, including modern techniques like 3D imaging, digital microscopy, and forensic databases, under the framework of the BNSS and BSA (2023). The research relies on secondary sources and doctrinal analysis, with no primary experimental data. Availability of India-specific empirical studies on toolmark error rates and validation is limited, and ethical practices are assessed indirectly through literature, statutes, and case laws.

[1203] De Kinder, J., & Bonfanti, M. (2005). "Automated Comparison of Striated Toolmarks: The BulletTRAX-3D System." *Forensic Science International*, Vol. 156, No. 2–3, pp. 163–172

[1204] Mnookin, J. L. (2008). "The Validity of Forensic Identification Science and the Legal Admissibility of Expert Evidence." *Brooklyn Law Review*, Vol. 73, No. 3, pp. 1201–1270.

[1205] Singh, R., & Sharma, P. (2022). "Ethical Accountability of Forensic Experts in India: Bridging Science and Justice." *Indian Journal of Forensic Legal Studies*, Vol. 4, No. 2, pp. 85–101.

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CHAPTER II

CONCEPTUAL FRAMEWORK OF TOOLMARK EVIDENCE

2.1 DEFINITION OF TOOLMARKS:

Toolmarks are **physical impressions, abrasions, cuts, or striations** left on a surface when a hard object comes into contact with it. These marks arise from the mechanical interaction between a tool and a substrate, which may be metal, wood, plastic, glass, or other materials commonly encountered at a crime scene. In forensic science, toolmarks are considered **critical** trace evidence because they can establish a connection between the tool, the suspect, and the criminal act[1206]. Each tool possesses unique characteristics arising from its manufacturing process, usage wear, and incidental damage over time. When a tool interacts with a surface, it leaves behind class characteristics (related to tool type, size, and design) and individual characteristics (microscopic irregularities unique to that particular tool). These unique marks are central to toolmark examination and comparison, forming the scientific basis for linking evidence to a specific instrument.

Forensic authorities, including the **FBI and Interpol**, define toolmarks as any trace evidence produced when a tool comes into contact with a surface, whether intentionally (e.g., breaking and entering) or accidentally. Toolmarks are often called **"silent witnesses"**, as they preserve information about the type of tool, the manner of its use, the force applied, and, sometimes, the sequence of events at the crime scene[1207]. The accuracy of toolmark examination directly affects the evidentiary reliability of findings and the ethical responsibility of forensic experts in judicial proceedings.

2.2 PRINCIPLES OF TOOLMARK IDENTIFICATION:

When a tool interacts with a surface, it transfers unique microscopic patterns that can be scientifically analyzed and compared. The objective of toolmark identification is to determine whether a particular tool was used to produce a specific mark, thereby establishing a physical link between the tool, the suspect, and the criminal act[1208]. The credibility of toolmark evidence depends upon adherence to certain scientific principles, standardized methodologies, and ethical examination practices, ensuring that conclusions drawn are objective, reproducible, and legally admissible.

2.2.1 Principle of Individuality:

The principle of individuality is the cornerstone of forensic toolmark identification. It is based on the scientific assumption that no two tools, even if manufactured in the same batch, possess identical microscopic characteristics.

- During manufacturing, tools acquire microscopic imperfections due to machining, cutting, grinding, or polishing processes.
- With continuous use, wear and tear introduce random irregularities, scratches, and striations that make each tool's surface unique and distinguishable.
- When such a tool interacts with a softer surface—such as metal, wood, or plastic—it transfers these microscopic irregularities in the form of striated or impressed marks.
- These marks act like a fingerprint of the tool, capable of identifying the exact tool used in committing the crime.

The individuality principle is supported by the Association of Firearm and Tool Mark Examiners (AFTE) Theory of Identification, which states that the correspondence of sufficiently unique microscopic patterns between two marks is the

[1206] Sharma, B. R., *Forensic Science in Criminal Investigation and Trials*, 6th ed., Universal Law Publishing, 2020, pp. 428–442

[1207] National Research Council (U.S.), *Strengthening Forensic Science in the United States: A Path Forward*, National Academies Press, Washington D.C., 2009, pp. 150–165.

[1208] Bunch, S. G., *Consequences of Error Rates in Forensic Toolmark Identification*, *Journal of Forensic Identification*, Vol. 56, No. 1, 2006, pp. 59–68.

basis for concluding that both were produced by the same tool.[1209]

2.2.2 Principle of Reproducibility:

The principle of reproducibility complements individuality by establishing that a tool will reproduce the same pattern of marks when used under similar conditions.

- It ensures that the microscopic characteristics observed on a crime scene mark can be replicated in the laboratory using the suspected tool, thereby validating the match.
- Controlled test impressions are made using the same tool and similar substrate materials, angles, and pressures.
- If the resulting test marks display the same pattern of striations or impressions as the crime scene marks, the reproduction confirms a scientific connection.

However, reproducibility is influenced by external factors such as:

- The angle and force of application,
- Type and hardness of surface material, and
- Degree of wear or corrosion of the tool.

2.2.3 Principle of Comparison:

The principle of comparison is the operational core of toolmark identification. It involves a systematic and microscopic evaluation of the questioned toolmark recovered from a crime scene and a test mark produced by the suspected tool.

The comparison process typically involves three levels of characteristics:

- **Class characteristics**: General attributes determined by the design or manufacturer (e.g., size, shape, type of tool).
- **Subclass characteristics**: Marks produced during the manufacturing process that may be shared among tools from the same production lot.
- **Individual characteristics**: Unique microscopic features resulting from random imperfections and wear, which are crucial for identification.

Comparison is performed using comparison microscopes, digital imaging, or 3D scanning technology, allowing examiners to analyze:

- The pattern alignment of striations or impressions,
- The depth, spacing, and contour of toolmarks, and
- The degree of correspondence between questioned and test marks.

A positive identification is made when sufficient corresponding individual characteristics are found with no unexplained differences. Conversely, an elimination is concluded when the toolmarks show distinct dissimilarities. If the correspondence is partial or unclear, the result is recorded as inconclusive—a practice reflecting ethical integrity and scientific caution[1210].

Together, the principles of individuality, reproducibility, and comparison form the scientific and ethical foundation of toolmark identification. These principles collectively uphold the credibility, admissibility, and ethical soundness of toolmark evidence, reinforcing its role as a reliable scientific proof in the era of the BNSS and BSA, 2023, which emphasize forensic accuracy and expert accountability in India's reformed criminal justice system.

2.3 MECHANISM OF TOOLMARK FORMATION:

The mechanism of toolmark formation lies at the heart of toolmark examination. The marks

[1209] National Institute of Standards and Technology (NIST), *AFTE Theory of Identification as it Relates to Toolmarks*, AFTE Journal, Vol. 30, No. 1, 1998, pp. 86–88.

[1210] Biasotti, A. A., "A Statistical Study of the Individual Characteristics of Fired Bullets," *Journal of Forensic Sciences*, Vol. 4 (1959), pp. 34–50.

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that are formed as a result of mechanical interaction, deformation, and friction during the tool's use, creates a unique pattern that reflects the tool's surface characteristics. Understanding this mechanism is essential for establishing a scientific basis for identification and ensuring evidentiary reliability in criminal investigations.[1211]

The mechanism of mark formation depends on three major factors:

1. The nature and hardness of both tool and surface.
2. The angle and direction of force applied.
3. The type of motion (sliding, striking, or pressing).

Toolmark formation involves a mechanical deformation process, primarily governed by the principles of **friction, pressure, and elasticity**:

- When a tool is pressed against a substrate, **elastic deformation** occurs first; if the force exceeds the material's yield strength, **plastic deformation** sets in, creating a permanent mark.
- The degree of deformation depends on the relative hardness of the materials and the applied load**.**
- The contact area determines whether the resulting mark will be a continuous striation (from sliding) or a localized impression (from pressing).

Understanding the mechanism of toolmark formation allows forensic experts to:

- Reconstruct the **manner of tool usage** (direction, force, and method).
- Determine the **type of tool** and its condition at the time of the offence.
- Establish a **link between the tool and the scene** through pattern comparison.
- Evaluate the **reliability** of evidence by assessing whether the mark was made intentionally or incidentally.

When coupled with modern technologies such as 3D surface scanning, digital microscopy, and automated toolmark databases, the analysis of formation mechanisms enhances both accuracy and objectivity, reducing examiner bias.

CHAPTER III

EXAMINATION AND MATCHING OF TOOLMARK EVIDENCE

3.1 TYPES OF TOOLMARKS AND IMPRESSION PATTERNS:

Toolmarks are impressions or striations produced when a hard object comes into contact with a softer surface, transferring its microscopic characteristics. Based on the nature of contact and motion involved, toolmarks are broadly classified into three main categories:

1. **Impressed toolmarks** are formed when a tool is pressed against a surface without lateral movement, leaving a three-dimensional indentation. Examples include hammer or punch impressions on metal or wood.
2. **Striated toolmarks**, also called sliding or scraping marks, result when a tool moves across a surface under pressure, creating fine parallel lines or grooves (as in screwdrivers or cutting tools).
3. **Combination marks** occur when both pressing and sliding actions happen simultaneously, resulting in mixed characteristics of both impression and striation.

Each mark carries unique microscopic features formed due to manufacturing defects, wear, corrosion, or repeated use, thereby providing the tool with individual characteristics that differentiate it from all others, even of the same make or model. The importance of these distinctions has been judicially acknowledged in

[1211] Brodbeck, L. et al., "Evaluating the Reproducibility and Accuracy of 3D Imaging for Toolmark Comparison," *Journal of Forensic Sciences*, Vol. 66, No. 5 (2021), pp. 1561–1572.

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State of Maharashtra v. Damu Gopinath Shinde, where the Court upheld forensic evidence linking a weapon to the crime through characteristic tool impressions.[1212]

3.2 COLLECTION AND PRESERVATION OF TOOLMARK EVIDENCE:

The accuracy of toolmark analysis begins at the crime scene. Improper handling or documentation can distort the microscopic details crucial for comparison. Hence, meticulous collection, preservation, and chain of custody are essential. Investigators must **first photograph the toolmark in situ using scale and oblique lighting** to capture its depth and striation clearly. This ensures a permanent record before the evidence is disturbed. If the object bearing the mark (e.g., door frame, metal lock) can be safely removed, it should be packaged carefully using soft materials to avoid abrasion.[1213]

Casting materials like dental stone, silicone rubber, or epoxy resin replicate fine microscopic details of the mark, preserving the original configuration for later examination. The three-dimensional cast allows for accurate laboratory comparison without risking damage to the original evidence.

In *Ramanand v. State of Himachal Pradesh* case[1214], the Supreme Court emphasized the importance of scientific methods in evidence gathering, holding that failure to follow proper forensic procedures could weaken the prosecution's case. Thus, careful collection and preservation not only protect evidentiary integrity but also uphold the credibility of forensic science in judicial proceedings.

3.3 LABORATORY EXAMINATION TECHNIQUES:

The laboratory examination of toolmark evidence transforms raw physical impressions into scientifically verifiable evidence admissible in court. The objective is to identify the tool responsible for a particular mark and to determine the manner in which it was used. This process involves a systematic, multi-stage examination integrating both traditional microscopy and modern digital technologies to ensure accuracy, reproducibility, and evidentiary reliability.

(a) Preliminary Examination and Documentation:

The foremost step involves careful visual inspection to note any observable features such as the type of mark (impressed, striated, or combination), the material of the substrate, and the general shape or direction of the impression. The evidence is photographed using high-resolution cameras under controlled lighting conditions, both with and without scales. Oblique and cross-lighting techniques are used to reveal depth, striations, and irregularities invisible to the naked eye. Detailed notes and sketches are prepared to record orientation, dimensions, and surface characteristics. Maintaining the chain of custody is crucial throughout this stage. Proper documentation ensures the traceability and integrity of the evidence when presented in court.

(b) Microscopic Examination:

After visual inspection, the toolmark is examined under magnification using **stereomicroscopes and comparison microscopes**.

- **Stereomicroscope** helps in the initial classification of marks, identification of class characteristics (e.g., tool type, shape, edge width), and detection of any trace material (like metal shavings, paint, or lubricants).
- **Comparison microscope** allows two toolmarks—one from the crime scene (questioned mark) and another produced under controlled laboratory

[1212] *State of Maharashtra v. Damu Gopinath Shinde* (2000) 6 SCC 269
[1213] Song, J. et al., "Establishing Objective Criteria for Toolmark Identification Using Quantitative Methods," *Forensic Science International*, Vol. 231 (2013), pp. 178–186.
[1214] *Ramanand v. State of Himachal Pradesh* (1981) 1 SCC 722

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conditions (test mark)—to be viewed side by side in real time[1215].

The examiner studies matching striations, ridge patterns, groove spacing, and micro-defects along the tool's working surface. The degree of correspondence between these features helps in determining whether both marks could have originated from the same tool.

(c) Casting and Replication for Comparison:

In cases where the original mark cannot be manipulated or observed from all angles, replica casting is employed. Using materials such as **silicone rubber, dental stone, or epoxy resin**, examiners produce three-dimensional casts of both the questioned and test marks. The casts replicate fine microscopic details of tool-surface interaction.

These casts are analyzed under the microscope to compare **depth, contour, and surface topography**, which helps in understanding the angle and force of tool application. The replication process also allows repeated examination without damaging the original evidence, which is particularly vital in judicial proceedings.

3.4 MATCHING, COMPARASION AND IDENTIFICATION ANALYSIS:

The goal of toolmark comparison is to establish whether a specific tool created a particular mark. This process follows the **principles of individuality and reproducibility**, meaning that every tool, due to microscopic irregularities, leaves unique patterns that can be reproduced under controlled conditions. This stage involves both **qualitative and quantitative evaluation** of class and individual characteristics, ensuring that conclusions are scientifically grounded and legally defensible.[1216]

3.4.1 Matching Methodologies:

Forensic experts employ multiple approaches to evaluate the correspondence between crime scene marks and test marks:

1. **Side-by-Side Comparison** – Placing the questioned and test marks next to each other under a comparison microscope to observe alignment of striations, ridges, and grooves. This traditional method remains foundational for visual verification.
2. **Juxtaposition Method** – Aligning the suspected tool with the mark to check contour fit and orientation. This method is particularly useful when the tool and marked surface are both available.
3. **Superimposition Method** – Overlaying digital images or 3D scans of the test and questioned marks to evaluate microscopic agreement. Transparency adjustments allow precise visualization of striations and patterns.
4. **Complex/Segmented Analysis** – In cases with multiple overlapping impressions, marks are divided into segments for independent comparison. Modern software assists in quantitative analysis of such complex patterns.
5. **Mechanical Fit Method** – While primarily used for fractured objects, this method confirms whether tool fragments or broken edges physically match crime scene evidence.

3.4.2 Identification Analysis:

After comparison, forensic examiners reach one of three possible conclusions:

1. **Positive Identification** – Sufficient agreement exists in individual characteristics to conclude that the marks were made by the same tool.
2. **Elimination** – Clear differences indicate the marks were produced by different tools.

[1215] Thompson, R. M. et al., "The Application of 3D Surface Topography Analysis to Toolmark Comparisons," *Forensic Science International*, Vol. 217 (2012), pp. 127–138.
[1216] Song, J. & Vorburger, T., "Three-Dimensional Surface Topography Analysis for Firearm and Toolmark Identification," *Measurement Science and Technology*, Vol. 24, No. 5 (2013), pp. 1–8.

3. **Inconclusive** – Evidence is insufficient or ambiguous to draw a definitive conclusion.

The **Association of Firearm and Toolmark Examiners (AFTE) Theory of Identification** provides a structured approach: when sufficient agreement exists in individual characteristics between a questioned mark and a test mark, it can be concluded that both originated from the same tool. However, the examiner must carefully consider environmental, procedural, and material factors that may alter the mark's appearance[1217].

3.5 MODERN ANALYTICAL TECHNIQUES:

Modern laboratories employ **3D digital imaging** to enhance precision and eliminate subjective bias. Tools such as confocal laser scanning microscopy (CLSM), focus variation microscopy, and scanning electron microscopy (SEM) create detailed three-dimensional surface models of toolmarks at microscopic resolution.

These technologies measure surface depth, striation angle, and topographical features with high accuracy, allowing numerical or statistical comparison. Digital profiles are stored in forensic databases like **NBTRD (National Ballistics and Toolmark Reference Database)** and international systems such as **IBIS (Integrated Ballistics Identification System)** for automated cross-comparison with other known samples.[1218]

3.6 LIMITATION AND QUALITY CONTROL:

Despite technological progress, toolmark examination faces limitations such as subjective interpretation, lack of universal standards, environmental damage to evidence, and tool wear variability. Differences in laboratory procedures and examiner training can affect reproducibility of results. Quality control measures—such as peer review, blind verification, proficiency testing, and adherence to ISO-accredited forensic standards—are essential to maintain evidentiary reliability[1219]. Ethical responsibility demands that experts report limitations transparently and avoid overstating conclusions, ensuring fairness and integrity in judicial outcomes.

The Supreme Court in *Murari Lal v. State of Madhya Pradesh*[1220], reiterated that expert opinion must be weighed carefully and corroborated independently. Thus, forensic integrity and ethical responsibility are fundamental to ensuring that toolmark evidence strengthens justice rather than distorts it.

CHAPTER IV

EVIDENTIARY RELIABILITY OF TOOLMARK EVIDENCE

4.1 ROLE OF FORENSIC EXPERT UNDER BSA ACT, 2022:

Forensic experts play a pivotal role in ensuring the accuracy, objectivity, and admissibility of toolmark evidence. Under the Bharatiya Sakshya Adhiniyam, 2023 (BSA) and the BNSS, 2023, experts are mandated to:

- Assist investigating officers in the collection, preservation, and documentation of toolmark evidence (Sec. 39, BNSS, 2023).
- Conduct scientifically validated laboratory examinations and generate reports adhering to recognized methodologies (Sec. 63, BSA, 2023).
- Provide objective expert testimony, highlighting limitations and degree of certainty in their conclusions.

Judicial pronouncements emphasize that the credibility of forensic experts depends on both methodological rigor and ethical compliance. The Supreme Court held that expert evidence is admissible only when based on recognized and

[1217] National Institute of Standards and Technology (NIST), *AFTE Theory of Identification as it Relates to Toolmarks*, AFTE Journal, Vol. 30, No. 1, 1998, pp. 86–88.
[1218] President's Council of Advisors on Science and Technology (PCAST), *Report on Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*, Executive Office of the President, Washington D.C., 2016.
[1219] Daeid, Niamh Nic, "Quality Assurance and Standards in Forensic Science," *Forensic Science International*, Vol. 167 (2007), pp. 121–126.
[1220] *Murari Lal v. State of Madhya Pradesh* (1980) 1 SCC 704

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tested scientific principles[1221]. Similarly, in *Ram Chandra v. State of Uttar Pradesh*[1222], the Court stressed the importance of corroboration and cautioned against over-reliance on expert opinion alone.

4.2 LEGAL TESTS FOR ADMISSIBILITY:

The **admissibility of toolmark evidence** is governed by multiple principles:

1. **Relevance and Materiality:** Evidence must be directly linked to the offence and capable of assisting the court in reaching a fact.
2. **Scientific Reliability:** Methods employed must be validated, reproducible, and free from undue subjectivity. Section 63 of the BSA, 2023, codifies this principle by requiring expert opinion to rest on established scientific methodology.
3. **Judicial Scrutiny:** Courts assess the **techniques, data, and conclusions** critically before accepting expert testimony.

Several landmark judgments illustrate this approach:

- *Murari Lal v. State of Madhya Pradesh* (1980) 1 SCC 704[1223]: Expert opinions must be corroborated with other evidence; the Court emphasized careful judicial evaluation of scientific testimony.
- *Tomaso Bruno v. State of Uttar Pradesh* (2015) 7 SCC 178[1224]: Courts recognized the evidentiary weight of technologically validated and digitally documented forensic evidence.

Legal tests now demand **transparency, reproducibility, and validation** in forensic procedures, ensuring that toolmark evidence is not only admissible but also reliable for adjudication.

4.3 RELIABILITY CONCERNS AND SCITENTIFIC VALIDATION:

Despite the technological advances in 3D imaging, digital databases, and automated comparison systems, **toolmark evidence is not infallible**. The main reliability concerns include:

- **Subjectivity in microscopic interpretation**: Even trained examiners may differ in evaluating subtle striations.
- **Environmental and material factors**: Marks may degrade due to weather, handling, or surface variability.
- **Lack of universal standardization**: Laboratories may employ varying methods for casting, imaging, and comparison.

To mitigate these risks, **scientific validation** of forensic methodologies is crucial. Techniques must undergo **peer review, proficiency testing, and statistical assessment** to quantify error rates. Digital and AI-driven tools now support **objective measurements and database-assisted identification**, enhancing reliability.[1225]

Judicial scrutiny complements scientific validation. Courts, while accepting the value of toolmark evidence, insist on **documented methodology, reproducibility, and corroboration**. As noted in the case[1226], forensic evidence must be carefully evaluated and cannot be treated as conclusive in isolation. Ethical responsibility requires that forensic experts disclose limitations and avoid overstating certainty, ensuring that evidence is both **scientifically credible and legally defensible**.

[1221] *State of Himachal Pradesh v. Jai Lal & Ors.* (1999) 7 SCC 280
[1222] *Ram Chandra v. State of Uttar Pradesh* (AIR 1957 SC 381)
[1223] Ibid, para 195
[1224] *Tomaso Bruno v. State of Uttar Pradesh* (2015) 7 SCC 178
[1225] Collins, C. H., "Forensic Science and Miscarriages of Justice," *Forensic Science Policy & Management*, Vol. 2, No. 1 (2011), pp. 1–7.
[1226] *State of Haryana v. Bhagirath* (1999) 5 SCC 96

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CHAPTER V

ETHICAL RESPONSIBILITY IN FORENSIC TOOLMARK EXAMINATION

5.1 CORE ETHICAL PRINCIPLES:

Forensic toolmark examiners are bound by **core ethical principles**, which guide all stages of evidence handling, analysis, and reporting:

- **Objectivity and Impartiality:** Experts must report findings based solely on observed data, avoiding personal bias or influence from law enforcement or prosecution.
- **Accuracy and Competence:** Examinations should be conducted using validated techniques and updated knowledge of forensic science. Section 63 of the **Bharatiya Sakshya Adhiniyam, 2023** mandates that expert opinion must rely on scientifically tested principles.
- **Integrity and Transparency:** Documentation, chain of custody, and methodological procedures must be clearly recorded, enabling independent verification and judicial review.
- **Confidentiality:** Sensitive case information must be safeguarded to prevent misuse.

These principles ensure that forensic testimony is **credible, reproducible, and ethically sound**, forming the moral backbone of forensic practice.

5.2 ETHICAL CHALLENGES AND BIAS IN FORENSIC TESTIMONY:

Despite formal guidelines, forensic experts face **ethical challenges** that may compromise evidence integrity:

- **Subjective Interpretation:** Microscopic evaluation of striations or impressions can be influenced by confirmation bias or prior knowledge of the case.
- **Pressure from Investigative Agencies:** Experts may experience implicit or explicit pressure to produce evidence supporting prosecution, risking partiality.
- **Technological Overreliance:** While AI, 3D imaging, and database matching enhance accuracy, blind trust in automated results without expert verification can lead to ethical lapses.

Historical and contemporary case studies illustrate these challenges. Globally, wrongful convictions have resulted from **overstated expert confidence or selective interpretation of toolmark evidence**, underscoring the need for rigorous adherence to ethical standards[1227]. Indian courts, in *Murari Lal v. State of Madhya Pradesh* (1980) 1 SCC 704, have emphasized that expert evidence must be cautiously evaluated, and bias or misconduct undermines judicial reliability.

5.3 ETHICAL FRAMEWORK AND ACCOUNTABILITY:

Accountability mechanisms are essential to prevent misconduct and ensure public trust in forensic science:

- **Professional Oversight:** Forensic laboratories must implement peer review, blind testing, and inter-laboratory verification to detect errors and minimize bias.
- **Reporting Standards:** Ethical guidelines require experts to clearly state limitations, avoid exaggeration of findings, and document all procedural steps.
- **Judicial Oversight:** Courts evaluate expert conduct and the ethical handling of evidence. In *State of Himachal Pradesh v. Jai Lal & Ors.* (1999) 7 SCC 280, the Supreme Court underscored that credibility depends not only on methodology but also on ethical compliance.

[1227] Krishnan, V. & Rajagopal, R., "Ethical Challenges in Forensic Practice: An Indian Perspective," *Indian Journal of Forensic Medicine & Toxicology*, Vol. 15, No. 3 (2021), pp. 231–238.

- **Frameworks for Redress:** Instances of ethical violations—such as selective reporting or misrepresentation of toolmark evidence—must be addressed through professional disciplinary boards, laboratory audits, and judicial review.

Together, these measures form an **ethical framework** ensuring that toolmark examination balances **scientific rigor with moral responsibility**, preventing miscarriages of justice and maintaining confidence in forensic practice.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

Toolmark evidence plays a pivotal role in linking instruments to criminal acts, but its reliability depends on **scientifically validated methods, meticulous collection, and ethical conduct** by forensic experts. Traditional techniques like side-by-side comparison, mechanical fit, juxtaposition, and superimposition remain foundational, while **modern methods** such as 3D imaging, digital databases, AI-assisted comparison, and SEM enhance objectivity and reproducibility and courtroom defensibility. Legal admissibility is guided by Section 63 of the Bharatiya Sakshya Adhiniyam, 2023**,** judicial scrutiny, and precedents emphasizes corroboration and methodological reliability but also by adherence to validated procedures, transparency, and cross-verification. Ethical responsibility ensures impartiality, integrity, and accountability, with peer review, standardized protocols, and judicial oversight reducing bias and errors. Recommendations include standardized procedures, scientific validation, ethical training, expansion of digital databases, judicial awareness, and interdisciplinary collaboration**.** With the integration of modern technology, ethical accountability, and legal rigor, toolmark evidence can reliably support justice while minimizing wrongful convictions, thereby strengthening the Indian criminal justice system.

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