

Legal Validation of Digital Forensic in Palmar and Plantar Ridge Analysis for Crime Scene Reconstruction: A Comprehensive Narrative Review

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Citation: Rajasree RS (2026) Legal Validation of Digital Forensic in Palmar and Plantar Ridge Analysis for Crime Scene Reconstruction: A Comprehensive Narrative Review. J Forensic Sci Criminol 14(2): 101

Received Date: August 04, 2026 **Accepted Date:** August 13, 2026 **Published Date:** August 18, 2026

Abstract

Digital forensic science has significantly advanced crime scene investigation by enabling the scientific identification, preservation and analysis of latent Ridge impression left by the palms of the hands and soles of the feet . Palmar and planter ridge pattern are unique and permanent for every individual, making them valuable biometric identifiers for establishing a person's presence, movement and interaction with object at the crime scene. with the development of digital imaging image, enhancement techniques, automated comparison system and artificial intelligence, forensic expert can now analyse impression with greater precision and efficiency than traditional method. Despite these technology and advancement the admissibility of digital generator. Evidence depends not only scientific accuracy, but also owned its legal validation. quotes require forensic techniques to be reliable, reproducible, transparent, and supported by recognised scientific standards before they can be accepted as the evidence. Variations in laboratory practises, Limited validation studies, technological disparities, and the absence of universally accepted protocols continued to raise concerned regarding the legal reliability of digital palmar and planter Ridge analysis.

The narrative review adopts a doctrinal and qualitative review methodology by examining the Bharathiya Sakshya Adhiniyan 2023, and the Bharathiya Nagarika Suraksha Sanhita 2023, relevant judicial decision, international forensic standards, scientific guidelines and peer reviewed literature on friction ridge examination and digital forensic practices. The review critically analyses the scientific basis of digital palmar and plantar Ridge analysis, its application in crime scene reconstruction and their legal principles governing its admissibility in criminal proceedings. It also evaluates issues relating to the method validation, standardisation, reproducibility, error rates, quality assurance and growing use of artificial intelligence in forensic comparison. The review concludes that the digital palmar and plantar ridge analysis has considerable potential to strengthen forensic investigation and support accurate crime scene reconstruction when supported by validated scientific methodologies, standardised forensic protocols, transparent expert reporting and robust legal framework that ensures the reliability and credibility of digital forensic evidence.

Keywords: Palmar ridge analysis ,Digital forensics, forensic science, Crime scene reconstruction, Legal validation

Introduction

Crime scene reconstruction is an important component of forensic investigation that seeks to establish the sequence of events before, during and after the commission of a crime.[1] Traditionally, investigators have relied on fingerprints, DNA profiling, blood stain pattern analysis, trace evidence and eyewitnesses testimony to reconstruct criminal incidence and identify offenders. Due to the technological advancement in forensic science it has evolved into digital forensic science and it has expanded the scope of forensic evidence by enabling the detection and analysis of latent Palmar (palm) and plantar(Sole) ridge impressions. These ridges pattern are unique and permanent for every individual making them reliable biometric identifiers for forensic identification. Latent ridge impression maybe deposited on floors, walls, furniture and other surfaces providing valuable information regarding an individuals presence, movement and interaction with object at a crime scene. Recent developments in digital imaging, image enhancement, authenticated comparison system and artificial intelligence significantly improve the accuracy, efficiency and reliability of ridge pattern examination which making palmar and plantar ridge analysis an increasingly valuable tool for crime scene reconstruction Particularly where fingerprints or DNA evidence are unavailable or incomplete.[2]

The forensic value of palmar ridge evidence was notably demonstrated in the *people v. Richard Allen Davis* (1993), case in the United States, During the investigation into the kidnapping and murder of Polly klass, investigators recovered a latent palm print from the victims bedroom that did not belong to any member of the household. Through forensic comparison the palm print was matching to Richard Allen Davis directly linking him to crime scene and contributing significantly to his conviction, this case highlighted the importance of palmers evidence in establishing the identity and presence of an individual, particularly when supposed to be used scientific forensic techniques. Despite such advancement, the admissibility of digital evidence, Jeev depends upon more Than technological accuracy. course require forensic methods to be scientifically valid, reproducible and supported by recognised known rate and transparent expert testimony. Legal validation has become an essential requirement for establishing that digital evidence is reliable and credible evidence capable of its judicial.

In India, the legal framework governing the admissibility of digital forensic evidence has been strengthened through the Bharathiya Sakshya Adhiniyam 2023, which recognizes expert opinion and electronic evidence while procedural aspects of criminal investigation are governed by Bharathiya Nagarik Suraksha Samhita 2023 (BNSS) and substantive criminal offences are addressed under the Bharatiya Nyaya Sanhita, 2023 (BNS). Although these statutes recognize digital forensic evidence and they do not specifically regulate the use of Plumer and plan analysis leaving significant regulate the use of palmar and plantar ridge analysis leaving significantly regulate the use of palmar and plantar ridge analysis which leaving significant question regarding standardization, validation and judicial acceptance. The narrated review examines the scientific foundation, technological development and legal principal governing digital palmar and plantar ridge analysis in crime scene reconstruction. Also the study argues that the scientifically validated methodologies, standardised forensic procedure and robust legal safeguards are essential to enhance the credibility and value of Digital Ridge analysis within the modern criminal system. Palmar and plantar friction ridge pattern are formed during fetal development and remain permanent throughout an individual's lifetime unless they are destroyed by severe injury or disease. These ridge characteristics frequently remain identifiable even after prolonged immersion of a body in water allowing forensic experts to recover and analyse valuable biometric evidence through appropriate preservation and imaging techniques. Their remarkable durability under adverse environmental conditions enhances their significance in post mortem identification and crime scene reconstruction particularly when fingerprints or DNA evidence are unavailable or severely degraded. The integration of digital imaging, image enhancement and automated comparison technologies has strengthened the scientific reliability of palmar and plantar ridge analysis in modern forensic investigations.



Figure 1. Workflow of Digital Palmar and Plantar Ridge Analysis

Literature Review

Scientific Basis of Palmar and Plantar Ridge analysis

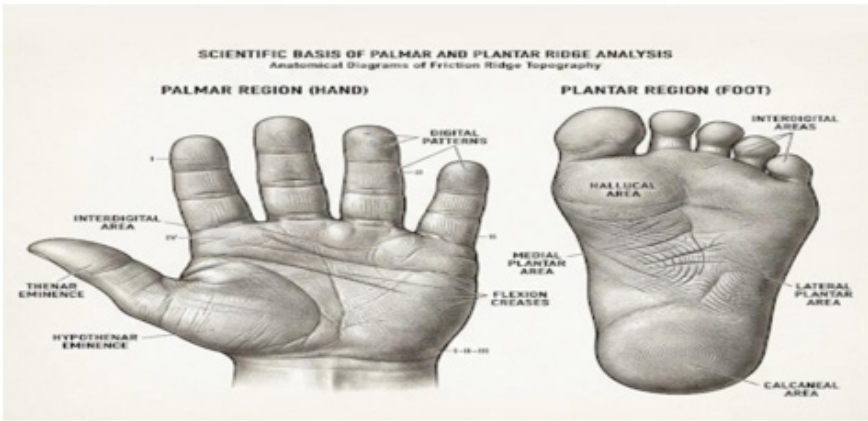


Figure 2. Palmar and Plantar Friction Ridge Topograph

Table 1. Distribution and Characteristics of Friction Ridge Patterns

Ridge area	Primary pattern types	Approximatepopulation frequency (%)
Palmar Region (Hand)	Loops,Whorls,Arches, Vestiges	Approximately 65% Loops,~30% Whorls, ~5% Arches
Plantar Region (Foot)	HallucalWhorls,Loops, Open Fields	Approximately 50% Whorls,~45%Loops,~5%Open Fields
Digital Areas (Fingertips)	Plain Arches, Tented Arches, Loops, Whorls	Approximately 60% Loops,~35% Whorls, ~5% Arches

Digital forensic tech technologies in Ridge analysis

Recent technological advancements have significantly improved the examination of latent ridge impressions. Digital imaging, image enhancement software, automated comparison system and artificial intelligence have increased the accuracy and efficiency of ridge analysis. Ashbaugh’s work on ridge comparison techniques introduced systematic approaches for analysing ridge characteristics. While later studies by Pardeep Kaur and Anil Verma highlights the role of Digital enhancement and automated matching system in improving forensic reliability. These technologies reduce examiner subjectivity and enable the identification of faint or partial Ridge impression that may otherwise remain and undetected.

Legal validation and admissibility of the digital ridge evidence

Although digital forensic technologies have strengthened the scientific basis of ridge analysis, their admissibility in judicial proceedings depends upon legal validation studies by Christopher K Thomas, John M Butler and other foreign scholars emphasize that scientifically reliable methods must demonstrate reproducibility, established error rates, validated procedures and compliance with recognised forensic standards. International guidelines issued by organisations such as the National Institute of Standards and Technology (NIST), the scientific working group on friction ridge analysis, study and technology (SWGFAST) and the international organisation for standardisation (ISO). Judicial decisions including *Daubert v Merrell Dow pharmaceuticals* continue to influence the evaluation of scientific evidence by requiring Courts to assess the reliability and validity of forensic techniques before admitting expert testimony [4].

Artificial intelligence and emerging developments

Artificial intelligence and machine learning have emerged as important developments in digital forensic science. [5] AI-assisted systems can analyse complex characteristics, improve matching efficiency and reduce processing time in large forensic databases. However, when it comes to the recent literature, it recognises that the use of AI also introduces concerns regarding algorithmic transparency, software validation, explainability and accountability. Researchers therefore argue that AI-generated forensic conclusions should be supported by rigorous scientific testing and human expert verification before they are relied upon in criminal proceedings.

Research Gap

The existing literature demonstrates significant progress in digital ridge analysis and forensic identification and comparatively limited attention has been devoted to legal validation of digitally enhanced palmar and plantar ridge evidence, particularly within the framework of Indian Bharathiya Sakshya Adhiniyam, 2023. Most studies focus either on scientific aspects of ridge analysis or general principles of forensic admissibility within limited integration of technological advancement, legal standards, and crime scene reconstruction. This review seeks to bridge that gap by critically examining the relationship between digital forensic innovation and legal validation to evaluate the evidential value of palmar and plantar analysis in contemporary criminal justice systems.

Review Methodology

This narrative review adopts a doctrinal and qualitative approach to examine the legal validation of digital forensic methods in palmar and plantar ridge analysis for crime scene reconstruction. The review is based exclusively on secondary sources and does not involve the collection or analysis of primary empirical data. Relevant legal provisions, judicial decisions, forensic science literature, peer-reviewed journal articles, government reports and international forensic standards were critically examined to evaluate the scientific reliability and legal admissibility of digital ridge analysis. The selected literature was analysed thematically to examine this scientific principle of palmar and plantar ridge analysis, recent developments in digital forensic technologies and the legal standards governing the admissibility of forensic evidence. Particular attention was given to issues of scientific validation, standardisation, reproducibility, quality assurance and expert testimony. The review synthesises the existing literature to identify current developments, challenges and future directions for strengthening the evidentiary value of digital palmar and plantar ridge analysis in crime scene reconstruction.

Critical Synthesis and Analysis

The reviewed treasure demonstrates that digital palmar and planter ridge Analysis has emerged as a promising tool for crime scene reconstruction by complimenting conventional forensic technique such as fingerprint examination, DNA profiling. Advances in digital imaging, image enhancement, automated comparison system, and artificial intelligence having significantly improve the detention and comparison of Latent ridge impression particularly where conventional evidence is unavailable or incomplete. These technological developments enhance the forensic efficiency and reduce examiner subjectivity thereby increasing the potential reliability of Ridge based identification. [6] The literature consistently emphasises that technological advancement along is insufficient to establish evidently value. The scientific reliability of digital ridge analysis depends upon validated methodologies, standardised examination procedure, quality Assurance measures and transparent documentation that enable consistent and reproducible forensic conclusions.

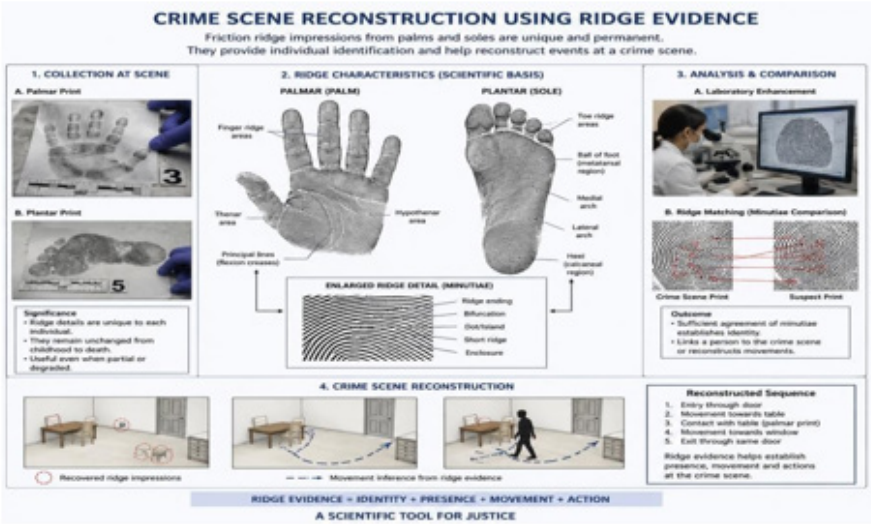


Figure 3. Crime Scene Reconstruction Using Ridge Evidence

From a legal perspective, the admissibility of digital palmar and planter ridge evidence requires complaints with established evidently standards governing expert opinion and electronic evidence. The introduction of artificial intelligence and automated comparison system has created new opportunity for improving forensic accuracy but has also raised concern regarding algorithmic transparency, validation, reproducibility and explainability. Existing studies indicate that differences in laboratory infrastructure, validation protocols and professional practices continue to affect the consistency of forensic findings across jurisdictions. These challenges highlighted need for harmonised forensic standards, regulatory proficiency testing and comprehensive validation studies. Accordingly the literature suggest that digital palmar and planter analysis can become a scientifically reliable and legally credible tool for crimes and reconstruction but it should be supported by rigorous validation , standardised forensic protocols, and effective expert interpretation capable of satisfying judicial requirements.[7]

Table 2. Statistical Efficacy of Ridge Evidence in Crime Scene Reconstruction

Evidence Type	AverageMinutiaePoints Required for ID	Success Rate in Latent Print Recovery (%)
Palmar Prints (Palm)	12 to 16 reliable minutiae points	Approximately 40% to 50% usable surface recovery
Plantar Prints (Sole)	12 to 16 reliable minutiae points	Approximately 25% to 35% usable surface recovery
Digital Prints (Fingers)	8to12reliableminutiae points	Approximately 75% to 85% high-clarity recovery

Conclusion

Digital Palmar and plantar ridge analysis has significant potential to strengthen the crime scene reconstruction and forensic identification. The admissibility and evidentiary value depends on scientifically valuated methods, standardised forensic protocols and compliance with legal standard. Strengthening validation procedure, quality assurance and expert reporting will enhance judicial confidence in digital ridge evidence. The key Takeaway is that digital palmar and plantar ridge analysis can serve as a reliable forensic tool only when scientific innovation is supported by robust legal validation and standardised practices. Digital palmar and plantar ridge analysis has emerged as a powerful forensic tool with the potential to transform crime scene reconstruction and criminal investigation particularly in complex offences such as homicide where conventional evidence may be limited or compromised. The integration of digital imaging, automated comparison system and artificial intelligence has significantly enhanced the detection and interpretation of latent ridge impressions which helps in improving forensic accuracy.

Statements and Declarations

Competing Interests

The author declares that there are no financial or non-financial competing interests related to this work.

Funding

The author received no financial support from any funding agency in the public, commercial, or not-for-profit sectors for the research, authorship, and/or publication of this article.

Author Contributions

Rajasree R.S. solely conceived the study, conducted the literature review, performed the legal and scientific analysis, interpreted the findings, drafted the manuscript, and approved the final version for publication.

Data Availability

No datasets were generated or analysed during the current study. All information presented in this narrative review was obtained from publicly available published literature, legal sources, and scientific documents.

Ethics Approval

Ethics approval was not required for this study because it is a narrative review based exclusively on published literature and did not involve human participants, animals, or identifiable personal data.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

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