

The Transformation of Criminal Evidence in Light of Forensic Sciences and Emerging Biometric Technologies: From Theory to Application

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Abstract

Evidence in criminal matters has been enumerated in Article 160 of the Islamic Penal Code of 2013 and includes confession, testimony, qasameh (oath-taking by relatives in homicide or injury cases), oath, and the judge's knowledge. The judge's knowledge is formed through documentation, indicators, and manifest presumptions and, in the narrow sense of the word, is obtained with the assistance of evidence. In all legal systems, evidence serves as the master key for proving crimes and establishing criminal liability. Today, due to the significant advances achieved in modern sciences and laboratory disciplines compared to previous decades, traditional evidentiary methods have been overshadowed, and scientific evidence has gained a prominent and distinguished role in the process of crime detection and proof. Without doubt, disciplines such as forensic biology, forensic chemistry, forensic physics, and biometrics (bio-identification sciences) provide the possibility to counter increasingly complex criminal methods with scientific and accessible approaches to discovering and proving crimes and establishing criminal convictions. This research endeavors to examine scientific evidence both theoretically and practically in separate chapters. Initially, the introduction presents the research problem, questions, and hypotheses. It also reviews prior studies and articles based on the key terms of this research. Subsequently, the objectives are outlined, including theoretical and applied studies of biological and biometric sciences, as well as the challenges and obstacles encountered in the use of such evidence. Furthermore, the necessity of coherence and coordination among the organizations responsible for this matter is analyzed. The study is applied in nature, employs a descriptive-analytical approach, and has been conducted using a library-based research method with recourse to scientific articles and academic journals. Data were collected through systematic note-taking and extraction from the relevant sources.

Keywords: biological sciences, biometric sciences, forensic biology, forensic chemistry, criminal evidence

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1. Introduction

Evidence in criminal matters is enumerated in Article 160 of the Islamic Penal Code of 2013, including confession, testimony, qasameh (oath-taking by relatives in homicide or injury cases), oath, and the judge's knowledge. The judge's knowledge refers to certainty derived from documentation, indicators, and manifest presumptions; in its narrower sense, it is attained through evidence. Because the proof of crime and the establishment of criminal liability in all legal systems depend on the existence of evidence, evidentiary mechanisms play a central role in criminal law and particularly in proving offenses (Saei & Saghafi, 2013). Article 162 of the Islamic Penal Code further stipulates that if evidence with inherent legal standing, such as confession and testimony, lacks the required religious or statutory conditions, it may serve as a judicial presumption, provided it leads the judge to knowledge when corroborated by other indicators (Roshan-qalb Deylami, 2021).

Similarly, the Code of Criminal Procedure refers extensively to the crime scene and its role in detecting and proving offenses. From Article 123 to Article 136, the Code addresses the inspection of the scene, preservation and analysis of crime scenes, and the collection and sampling of physical traces left behind, which are key duties of the investigating magistrate and judicial officers during preliminary investigations (Aghajannia et al., 2022). Regarding adjudication and verdict issuance, Article 360 of the Code of Criminal Procedure provides: "Whenever the accused explicitly confesses to committing a crime in a manner leaving no doubt regarding the truthfulness and voluntariness of the confession, the court shall issue a judgment based on the confession." This provision implies that confession is not automatically sufficient to establish guilt and must align with surrounding circumstances, indicators, and presumptions — among which scientific evidence is crucial (Babaei & Shirzad, 2021).

When a case is brought forward, the judge forms knowledge and cognitive certainty about the subject matter, aiming at personal conviction grounded in judicial presumptions. The philosophical justification for accepting the judge's knowledge in issuing verdicts derives from scripture, prophetic tradition, and rational reasoning (Saei & Saghafi, 2013). Historically, the Prophet Muhammad (peace be upon him) and Imam Ali are reported to have judged cases based on their own knowledge, and eminent Shi'a jurists such as Shahid Thani and Shaykh Tusi have emphasized its evidentiary weight. For example, in establishing lineage, the high reliability of DNA testing — exceeding 99% — logically compels its acceptance (Rezaei, 2010).

The evidentiary weight of the judge's knowledge is generally regarded as superior to that of confession and testimony. Article 1276 of the Civil Code states that confession is valid only if its falsehood is not established before the judge. Article 1324 of the Civil Code adds that the judge's knowledge is admissible in cases that can otherwise be proved by testimony but must complement other forms of evidence. Thus, when an official document exists as evidence, the judge's knowledge alone may not suffice to render judgment. Furthermore, in certain offenses such as adultery (zina), the judge's knowledge cannot independently establish guilt (Roshan-qalb Deylami, 2021). Shi'a jurisprudence generally considers the judge's knowledge fully authoritative, whereas most Sunni jurists reject its absolute probative force due to concerns about judicial abuse or public suspicion (Saei & Saghafi, 2013). Some Shi'a scholars restrict the evidentiary scope of judicial knowledge based on the prophetic saying "I judge between you according to evidence and oaths," whereas others, such as Ibn Idris, accept the judge's knowledge in matters involving private rights but not divine rights (Saei & Saghafi, 2013).

The primary goal of criminal proceedings is to uncover the truth and identify the real perpetrator, and evidence serves as the essential tool to achieve this aim. One of the most important advances in this respect has been the integration of scientific evidence, beginning with the meticulous handling of crime scenes — preserving and analyzing physical materials, taking photographs, and employing other methods of identity detection (Jalili & Mahmoudi, 2014). Disciplines such as forensic engineering, forensic medicine, biological sciences, and biometrics provide modern tools for judges to acquire reliable knowledge (Johnson et al., 2024). In the past, criminal investigations relied mainly on observation and interpretation of physical clues. Notably, the Chinese used fingerprints for document authentication as early as 700 BCE. In 1810, the first chemical analysis for document verification took place in Germany (Niko-Akhlagh-Rad & Khodaiean, 2007). In 1813, Mathieu Orfila of the University of Paris, recognized as the father of modern toxicology, published the first textbook on forensic toxicology and pioneered the evaluation of blood and semen stains. In 1836, Scottish chemist James Marsh introduced arsenic

detection to prove poisoning, and in 1839, H. Bayard examined sperm identification using validated microscopic methods (Rezaei, 2010).

Nonetheless, multiple challenges persist in the admissibility and use of such evidence within criminal law, including legislative ambiguities, judicial inconsistency, and practical implementation obstacles (Nasiri & Bahrami, 2019). Debates within Islamic jurisprudence on the status of scientific evidence are longstanding. Some legal scholars, invoking Quranic texts and traditions such as the principle “hudud are repelled by doubts,” argue for restricting criminal proof to explicitly prescribed means. Others maintain that no clear scriptural basis limits the forms of evidence and that the higher aims of Sharia — ensuring justice and safeguarding legitimate interests — justify embracing modern scientific proof (Roshan-qalb Deylami, 2021). Although the 2013 Islamic Penal Code mentions traditional evidence types like confession and testimony, closer analysis shows that the legislator emphasizes the instrumental role of evidence in discovering the truth. Where scientific indicators contradict traditional proof, courts should not mechanically rely on confession or testimony (Aghajannia et al., 2022).

Additional systemic barriers also hinder the practical deployment of scientific and biometric evidence: insufficient financial resources, shortage of specialized personnel, limited training for experts, fragmentation among responsible agencies, inadequate regulatory frameworks on expert work, and weak protections for individual privacy (Kotsoglou & Oswald, 2020). This study addresses these challenges and explores practical solutions for strengthening the credibility and operationalization of scientific evidence in Iranian criminal proceedings.

2. Challenges Related to Forensic Botany

2.1. Scientific and Technical Challenges

One of the most significant barriers in forensic botany is the immense diversity of plant species and their morphological similarities. Determining the exact species and subspecies — particularly in regions with diverse vegetation or the presence of invasive and hybrid plants — is difficult and sometimes requires long-term analysis even by experienced botanists (Jalili & Mahmoudi, 2014).

Another complexity arises from the influence of environmental conditions on plant structures. Variations in temperature, light, humidity, soil composition, and pollutants can alter the morphological and chemical characteristics of plant samples, changing leaf color, seed structure, or tissue chemical composition. These changes directly affect the accuracy of results, especially in cases where there is a considerable time gap between the crime event and sample collection (Roshan-qalb Deylami, 2021).

The management of extremely small or degraded plant evidence is another major technical issue. In many crime scenes, plant traces appear only as pollen particles, microscopic wood fragments, or tiny fibers. Identifying these requires highly sensitive technologies such as advanced high-resolution microscopy or DNA barcoding systems, which are costly or limited in availability in many countries (Johnson et al., 2024).

Even in the domain of plant DNA technology, there are serious constraints. Extracting DNA from woody tissues or aged and decayed seeds is difficult, and global genetic databases do not fully cover all plant species. This limitation reduces the ability to quickly match laboratory results to existing data and undermines rapid, reliable identification (Rezaei, 2010).

2.2. Operational Challenges at the Crime Scene

Collecting, packaging, and preserving plant samples is more complex than handling other physical evidence. The risk of cross-contamination is very high, and even unintended contact with clothing, skin, or drying tools can alter sample composition. Strict transportation standards — such as using moisture-proof containers or sterile bags — are essential to maintain evidentiary integrity (Aghajannia et al., 2022).

Another issue is the lack of specialized teams among police and forensic personnel. In many organizations, plant identification tasks are left to general crime scene investigators who lack specialized botanical knowledge, increasing the risk of misidentification and flawed analysis (Babaei & Shirzad, 2021).

Time is also a critical factor affecting the reliability of plant evidence. Seasonal changes, plant growth or wilting, and natural decay can destroy vital information. Therefore, the time interval between crime scene discovery and sample collection must be minimized to preserve data reliability (Roshan-qalb Deylami, 2021).

2.3. Legal and Judicial Challenges

A fundamental legal barrier is the acceptance of plant-based evidence in the judicial system. Many judges and lawyers lack sufficient scientific familiarity with forensic botany and rarely consider botanical data as strong proof. This skepticism can undermine the evidentiary weight of plant analysis, even when laboratory results are scientifically accurate and credible (Saei & Saghafi, 2013).

Another major issue involves evidentiary standards and the chain of custody. Like other types of forensic evidence, plant samples must undergo strict documentation, including precise recording of the time and place of collection and controlled preservation. Any lapse in this chain can render the evidence inadmissible in court (Kotsoglou & Oswald, 2020).

Moreover, the absence of specific regulations and procedural guidelines in many jurisdictions means there is no standardized framework for the collection, testing, reporting, and courtroom presentation of botanical evidence. This legal gap has relegated forensic botany to a peripheral role in criminal proceedings (Nasiri & Bahrami, 2019).

2.4. Interdisciplinary Challenges

Forensic botany is inherently interdisciplinary and requires systematic collaboration among botanists, forensic scientists, biological laboratory experts, and specialists in emerging technologies. Poor coordination among these groups often leads to incomplete data or fragmented conclusions (Johnson et al., 2024).

The use of innovative technologies, such as artificial intelligence for automated plant species recognition through imagery or DNA data, holds considerable promise. However, these tools are not yet widely or uniformly integrated into forensic processes and face limitations such as incomplete reference databases, high costs, and the need for localized, validated models (Yadav et al., 2020).

This overview shows that although forensic botany has high scientific and practical value, its judicial and investigative use faces numerous barriers. Overcoming these obstacles requires a combination of specialized knowledge, legal support, technological development, and targeted training (Roshan-qalb Deylami, 2021).

3. Challenges and Barriers in the Use of Fingerprints

Fingerprint analysis has long been recognized as one of the most important tools for identification and personal authentication in forensic science, and its evidentiary reliability is nearly unquestioned in many legal systems (Klontz & Jain, 2013). However, the use of this method also encounters several challenges that can affect its accuracy, reliability, and admissibility.

The first barrier involves the poor quality of prints obtained from crime scenes. Often, fingerprints left behind are incomplete, unclear, or distorted due to superficial contact, surface contamination, perspiration, the presence of dust, grease, or gloves. Environmental factors such as humidity, temperature, dust, direct light, or the passage of time can further degrade or erase ridge details (Jain & Feng, 2011).

Another issue is the potential for false matches when dealing with partial or degraded prints. Although the probability of two complete prints being identical is negligible, partial similarities among certain ridge patterns can increase the risk of identification errors (Best-Rowden et al., 2014). Automatic Fingerprint Identification Systems (AFIS) also face technical limitations, occasionally producing false positives when analyzing poor-quality or distorted samples, which can lead to judicial errors (Qaderi & Sohrabi, 2020).

During fingerprint collection, the extreme sensitivity of the process means that any unintended contact or pressure can destroy or contaminate evidence. In some regions or agencies, there is a shortage of advanced detection and lifting tools, such

as specialized powders, lifting tapes, or high-resolution imaging systems, complicating the process (Roshan-qalb Deylami, 2021). Additionally, insufficient training of crime scene officers in properly recovering and preserving prints can compromise their evidentiary value (Babaei & Shirzad, 2021).

There are also deliberate efforts by offenders to alter or eliminate their fingerprints through methods such as burning fingertips, surgery, or using chemical agents, which present further operational challenges (Javidi & Davari, 2021).

From a legal perspective, one key issue is the overreliance on fingerprints as “conclusive proof.” This belief can lead to overlooking potential human or technical errors. Furthermore, maintaining an unbroken chain of custody is crucial; any failure in documentation or secure handling can result in courtroom inadmissibility (Kotsoglou & Oswald, 2020). Differences in standards and admissibility criteria across jurisdictions also hinder the rapid and effective use of biometric information in international cooperation (Nasiri & Bahrami, 2019).

Ethical and interdisciplinary concerns are also significant. The widespread use of fingerprints in biometric databases and integration with artificial intelligence systems amplifies the need for clear legal frameworks to protect individual privacy (Yadav et al., 2020). Long-term storage of biometric data raises legal and ethical questions about retention periods and permissible uses. Moreover, emerging technologies such as 3D printing and artificial fingerprint simulators increase the risk of spoofing and sensor deception, making continuous technological updates in authentication systems imperative (Best-Rowden et al., 2014).

Taken together, these challenges demonstrate that while fingerprint evidence remains a powerful tool in criminal justice, its sustainable reliability depends on scientific rigor, technological advancement, legal safeguards, and ethical considerations (Johnson et al., 2024).

4. Challenges Related to Biometric Facial Recognition Technology

Biometric facial recognition technology — which relies on analyzing the unique features of a person’s face to authenticate or identify individuals — has become one of the most widely used tools in security, law enforcement, and even public and commercial services. Despite its significant advantages, the technology faces multiple barriers that can be examined across technical, operational, legal, and ethical dimensions.

From a technical perspective, the most important challenge concerns accuracy and error rates. Facial recognition systems perform reliably in controlled environments but show higher error rates under real-world conditions where lighting, camera angle, camera quality, and individual appearance changes (such as wearing masks, glasses, facial hair, or makeup) vary significantly (Best-Rowden et al., 2014). Moreover, the technology depends heavily on the quality and completeness of existing databases; if the data is insufficient or low quality, the results become less reliable (Yadav et al., 2020). Physiological changes due to aging or certain medical conditions can also impair accurate recognition (Johnson et al., 2024).

On the operational level, deploying facial recognition in public spaces or large events encounters issues of data dispersion and image crowding. The quality of captured images may be inadequate for precise algorithmic analysis, especially under adverse weather or in crowded environments (Klontz & Jain, 2013). Additionally, there is an increased risk of hacking or unauthorized access to stored images and biometric data, which raises the threat of identity theft or privacy breaches (Javidi & Davari, 2021).

From a legal standpoint, a fundamental challenge is the absence of comprehensive and harmonized regulatory frameworks governing the collection, storage, and use of facial data. In some jurisdictions, there are no clear rules on the level of access granted to police, corporations, or other institutions, which may lead to misuse or violations of citizens’ rights (Kotsoglou & Oswald, 2020). The admissibility of facial recognition results as evidence in courts is sometimes questioned, especially when the system’s error rates are unclear or the algorithms used lack transparency (Nasiri & Bahrami, 2019).

On the ethical and social side, privacy concerns are paramount. Extensive deployment of facial recognition in public spaces can create a pervasive sense of surveillance and limit individual freedoms (Roshan-qalb Deylami, 2021). Moreover, research has shown that some facial recognition algorithms perform less effectively when identifying individuals with diverse skin tones

or ethnic features, potentially leading to systemic bias and discrimination (Johnson et al., 2024). There is also the risk of spoofing attacks, where high-quality photos, videos, or 3D masks are used to deceive recognition systems (Yadav et al., 2020).

Finally, the mass collection and indefinite retention of facial data without sufficient transparency and control can lead to massive, unregulated databases, where any data breach or misuse would have severe consequences for individual and collective security (Javidi & Davari, 2021). These combined challenges show that while facial recognition is a highly effective tool across various domains, responsible and sustainable use requires careful attention to technical accuracy, data security, legal clarity, and ethical implications.

5. Challenges Related to Forensic Medicine

Forensic medicine — as one of the core pillars of uncovering truth and delivering justice — plays a decisive role in determining causes of death, analyzing injuries, identifying individuals, and evaluating biological evidence. Despite its importance, the practical and scientific application of forensic medicine faces multiple challenges across technical, legal, managerial, and ethical dimensions.

A major technical and resource-related challenge is the lack of specialized equipment and infrastructure. Many forensic medical centers, particularly in underserved regions, lack advanced laboratories, modern imaging systems, or precise tools for DNA and toxicological analysis (Rezaei, 2010). This shortage can delay or compromise the accuracy of cause-of-death determinations and other vital analyses. Additionally, the shortage of highly experienced professionals, especially in subspecialties like forensic pathology, anthropology, and toxicology, often results in incomplete or lower-quality examinations (Roshan-qalb Deylami, 2021).

From a scientific perspective, forensic medicine must contend with the complexities of analyzing biological data. Natural postmortem decomposition, environmental exposure such as temperature and humidity, or contamination can hinder accurate determination of time and cause of death (Babaei & Shirzad, 2021). In complex crime scenes, the coexistence of human, animal, and plant evidence requires multidisciplinary approaches, which are not always integrated into the organizational structure of forensic institutions (Jalili & Mahmoudi, 2014).

On the operational side, maintaining the chain of custody remains a critical challenge. Any flaw in documenting the collection, transfer, or storage of biological samples can undermine their admissibility in court (Kotsoglou & Oswald, 2020). Time pressure in high-profile cases — especially those involving organized crime or intense media attention — can also push forensic experts to issue findings hastily, sometimes compromising accuracy (Johnson et al., 2024).

From a legal and judicial viewpoint, another challenge is how forensic findings are accepted and interpreted by judges and lawyers. Some judicial systems lack standardized guidelines for assessing forensic reports, leading to disagreements and potential misinterpretations (Saei & Saghafi, 2013). In addition, inconsistencies between domestic laws and international standards can hinder cross-border cooperation in criminal cases (Nasiri & Bahrami, 2019).

The ethical dimension is equally significant. Respecting the privacy of deceased individuals and their families, the responsible communication of sensitive results, and preventing unauthorized use of biological data are vital concerns (Yadav et al., 2020). Furthermore, political or media pressures may sometimes threaten the independence and objectivity of forensic experts, influencing scientific conclusions (Roshan-qalb Deylami, 2021).

Overall, due to its sensitive and complex nature, forensic medicine — while essential for justice — requires continuous investment in modern equipment and professional training, the development of clear legal and ethical frameworks, and the strengthening of interdisciplinary cooperation to ensure its findings remain accurate, impartial, and reliable within judicial processes (Johnson et al., 2024).

6. Challenges Related to Traffic Accident Expert Analysis

Traffic accident expert analysis, as a key element in judicial and insurance proceedings for road traffic incidents, is responsible for determining the cause and mechanism of the accident, assessing the degree of fault or negligence of each party,

and identifying contributing conditions based on physical evidence, technical data, and scientific analysis. Despite its importance, conducting accident reconstruction and expert assessment faces multiple challenges that can affect the accuracy and reliability of outcomes.

A fundamental challenge is the shortage or poor quality of physical evidence at the accident scene. Frequently, impact marks, tire skid traces, the positioning of vehicles and their stopping points, as well as the exact placement of objects and individuals, are altered before experts arrive — often due to emergency services' interventions or the movement of vehicles to restore traffic flow (Aghajannia et al., 2022). This alteration complicates trajectory reconstruction and speed estimation. Environmental conditions such as rain, snow, darkness, or heavy traffic can further erase critical traces (Roshan-qalb Deylami, 2021).

From a technical perspective, experts face the complexity of modeling collision mechanics, precisely determining impact angles and vehicle speeds, and reconstructing the sequence of pre-impact events (Johnson et al., 2024). Many centers lack advanced measurement devices or modern technologies such as 3D scene scanning and digital simulation tools, limiting analytical precision (Qaderi & Sohrabi, 2020). Additionally, in cases where vehicles are severely damaged or have been repaired before inspection, retrieving original evidence becomes difficult (Babaei & Shirzad, 2021).

In the operational dimension, timely on-site presence of qualified experts is vital. Any delay reduces the availability of fresh and reliable evidence. The shortage of well-trained accident reconstruction professionals and high caseloads often result in reports based largely on indirect data or witness interviews, increasing the risk of bias or error (Saei & Saghafi, 2013).

From a legal perspective, disputes frequently arise over the interpretation of expert opinions. The absence of uniform guidelines and clear standards for drafting accident reports leads to inconsistent judicial or insurance evaluations of similar incidents (Kotsoglou & Oswald, 2020). Additionally, external pressures — such as economic or political influences — and the potential dependency of experts on one of the parties can challenge impartiality and independence (Nasiri & Bahrami, 2019).

On the ethical and social side, maintaining neutrality under pressure from involved parties, protecting the rights of victims and defendants, and safeguarding the privacy of personal data in reports are critical issues (Yadav et al., 2020). The integration of new technologies — including data extraction from driver-assistance systems, surveillance cameras, and vehicle GPS — while technically beneficial, raises concerns about personal privacy (Klontz & Jain, 2013).

Ultimately, to enhance the accuracy and credibility of accident expert analysis, there is a pressing need to adopt modern reconstruction tools, provide continuous specialized training for experts, establish standardized regulations, and implement transparent protective systems to prevent non-scientific influences from affecting outcomes (Johnson et al., 2024).

7. Challenges Related to Scientific Evidence

One major issue in the field of forensic genetics, despite its exceptionally high accuracy and strong scientific foundation, is the potential for deliberate fraud and manipulation by professional criminal networks (Rezaei, 2010). For example, the use of stem cell or bone marrow transplants can alter an individual's genetic profile, making reliable identification difficult or even impossible. Another deceptive tactic involves criminals planting foreign biological material — such as pieces of clothing, someone else's blood, sperm, or hair — at the crime scene to mislead investigators and create false suspicion (Roshan-qalb Deylami, 2021).

Another critical challenge is the fragmentation of forensic responsibilities and contradictory expert opinions in certain cases (Saei & Saghafi, 2013). A notable example is a suspicious death case in Isfahan, where an initial scene investigation by the crime scene unit reported a skull fracture and visible pooling of blood beneath the deceased's head. However, after the body was transferred to forensic medicine and examined, no mention of hemorrhage or skull fracture was included in the autopsy report, and two months later, the cause of death was concluded as aluminum phosphide poisoning (rice tablet). Because the body had been buried after the initial autopsy, the court was forced to issue an exhumation order for a second examination, illustrating the complications caused by inconsistent expert findings (Johnson et al., 2024).

This underscores the need for integrated and multidisciplinary forensic teams to conduct critical scene examinations cohesively and avoid divergent or conflicting reports (Babaei & Shirzad, 2021).

Moreover, for crime scene analysis and identity verification processes, utilizing **private sector specialists** under strict security and confidentiality frameworks — in collaboration with the Ministry of Health — could enhance accuracy and responsiveness. Private entities often possess advanced expertise, better equipment, and higher capacity for answering technical queries efficiently (Kotsoglou & Oswald, 2020).

Overall, strengthening scientific evidence reliability requires not only cutting-edge technologies and specialized knowledge but also coherent organizational structures, inter-agency collaboration, and clear regulatory frameworks to prevent misuse or conflicting interpretations in the judicial process (Nasiri & Bahrami, 2019).

8. Challenges in the Use of Biometric Evidence for Identity Verification

Biometric evidence in identity verification — including fingerprints, facial recognition, palm prints, iris patterns, human voice, and even behavioral traits — is widely recognized as a powerful and relatively precise tool in forensic science, border control, and security operations. However, the use of biometric data faces a series of challenges that can affect its reliability, accuracy, and admissibility.

One of the most significant challenges is accuracy and error rates. No biometric system achieves 100% accuracy under real-world conditions. Physiological changes such as aging, disease, scars, or surgery, as well as temporary variations like fatigue or physical stress, can alter a person's biometric features and complicate exact matches with stored data. Environmental factors such as poor lighting, dust, humidity, or low-quality equipment also increase the likelihood of recognition errors.

From a technical perspective, heavy reliance on the quality of databases is a serious limitation. If initial data were not collected accurately or are incomplete, even advanced algorithms cannot deliver reliable results. Cyberattacks and database breaches pose an additional risk: unlike passwords, biometric data cannot be changed once compromised. Spoofing and simulation attacks — such as the use of artificial fingerprints, 3D masks, or voice imitation — remain a real threat to biometric systems.

From a legal viewpoint, the judicial acceptance of biometric evidence remains a concern. In some legal systems, doubts about scientific validity or the risk of system error lead judges to hesitate in considering biometric data as conclusive proof. Furthermore, the lack of unified standards for collecting, processing, and storing biometric information results in inconsistent evidentiary quality and admissibility across countries and even among domestic institutions.

On the ethical and social side, protecting privacy is a primary concern. Widespread and uncontrolled use of biometric data, especially in public surveillance systems, can create a sense of constant monitoring and restrict individual freedoms. Moreover, some biometric algorithms have been shown to perform less accurately for certain ethnic or gender groups, raising the risk of systemic bias and discrimination.

From an operational standpoint, the shortage of well-trained experts and the absence of precise protocols for handling biometric evidence lead to human errors during collection, interpretation, and recording. Long-term storage of massive biometric datasets without robust security infrastructure increases the risk of data breaches and misuse.

In summary, while biometric evidence provides significant security advantages and speed in identification, its effective and responsible use requires careful attention to technical precision, data security, legal clarity, and ethical safeguards to ensure it remains credible, reliable, and admissible in forensic and security contexts.

9. Barriers and Challenges in Person Identification and Crime Detection through Images

Person identification and crime detection using images is a fundamental tool in criminal investigations and forensic policing, benefiting significantly from advances in image processing and artificial intelligence. However, this field faces multiple barriers that affect the accuracy, reliability, and evidentiary value of visual evidence.

From a technical and scientific perspective, low image quality, poor lighting, unfavorable angles, subject movement, or excessive distance from the camera reduce the usable details in images. Environmental factors such as fog, rain, or glare also disrupt analysis. Deliberate changes in appearance, including masks or makeup, and natural changes like aging, weight

fluctuation, or surgery make matching images to real individuals more complex. Even advanced facial recognition algorithms can fail under uncontrolled conditions, and the absence of reference markers in images makes dimension and distance analysis unreliable.

On the operational side, the absence of integrated image databases and limited information-sharing between agencies delay access to relevant images. Analyzing and processing vast amounts of visual data requires computing resources and skilled specialists that are not always available. Differences in protocols among police, judicial authorities, and security organizations, as well as the risk of image deletion or manipulation before official registration, create further complications.

From a legal and judicial perspective, the admissibility of photos and videos as courtroom evidence is always under scrutiny due to the potential for digital manipulation and poor quality. Any break in the chain of custody reduces evidentiary credibility. The lack of clear national and international standards for image analysis and interpretation, along with the difficulty of verifying the authenticity of image sources (such as cameras, mobile phones, or social media platforms), adds to the complexity.

On the ethical and social front, large-scale image collection and analysis, especially in public spaces, risk violating privacy and creating a pervasive surveillance environment. Algorithmic bias in identifying certain racial or gender groups can lead to systemic injustice. There is also the risk of misuse of images for political or extrajudicial security purposes, undermining public trust.

Emerging technological challenges, particularly the rise of deepfake technology and sophisticated image manipulation tools, have made authenticity verification increasingly difficult. AI-driven facial reconstruction and precise alteration of appearance threaten the reliability of visual evidence. Additionally, urban surveillance networks generate massive amounts of image data, requiring highly complex and costly infrastructure for secure storage and analysis.

Overall, effective person identification and crime detection through images demand simultaneous strengthening of technical infrastructure, the development of clear legal standards, robust data protection, and adherence to ethical principles to ensure this powerful tool can support justice without undermining citizens' rights.

10. Conclusion

Human beings have always had an inherent tendency toward social life; from prehistoric times of cave dwelling and hunting for survival to today's advanced and urbanized societies, the fulfillment of human desires, needs, and aspirations has depended on social interaction. Isolation from community life has long equated to vulnerability and destruction. Recognizing the necessity of social order, humans began creating basic rules to prevent chaos and control antisocial behavior, such as the ancient Babylonian Code of Hammurabi, carved on stone and displayed publicly.

As populations grew and scientific, cultural, and civic advances emerged, humanity required stronger social order and control over interpersonal relations. Fair access to social resources, achieving collective goals, fostering healthy competition, and preventing disorder demanded structured governance. These needs led to the establishment of legislative bodies and judicial systems to prosecute offenders and uphold justice. As human societies, science, and technology evolved, laws also progressed — shifting from simple traditional codes to sophisticated, adaptive legal frameworks, and emerging as a formal discipline: the science of law.

Law today governs all aspects of public and private life — including criminal and civil matters — through legislatures, courts, and enforcement agencies. This study focused on the functional role of biological and biometric sciences in proving crimes and the challenges associated with their application. While confession and testimony remain legally significant, their credibility is often undermined by false statements and coerced confessions, reducing their status as decisive evidence. Consequently, modern criminal adjudication increasingly relies on scientific proof.

Advances in forensic disciplines such as biology, chemistry, physics, biometrics, and forensic medicine have transformed crime detection and evidence collection. Effective use of these sciences demands careful on-site evidence collection, precise packaging, secure transfer, and rigorous laboratory analysis, ensuring accurate linkage between evidence, crime scenes, and suspects. Modern crime-solving resembles assembling a puzzle — each piece of evidence complements the others.

Nevertheless, multiple barriers remain: legislative and judicial inconsistencies, limited human and financial resources, outdated tools and technologies, and the sophistication of professional criminals who employ complex countermeasures.

Overcoming these issues requires continuous scientific development, modernization of forensic tools, robust training, legal and procedural clarity, and collaboration between public institutions and qualified private sector experts.

By embracing interdisciplinary knowledge, advanced technology, and international best practices, legal systems can strengthen the evidentiary value of scientific proof, improve the accuracy of criminal adjudication, and respond effectively to the complexity of contemporary crime.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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Conflict of Interest

The authors report no conflict of interest.

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