

Iris Applications in Forensic Ophthalmology: Promise, Limitations, and the Future Directions

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Abstract

Human iris, with its highly complex, stable, and unique patterns, has gained increasing attention as a reliable biometric modality. In forensic ophthalmology, iris recognition presents significant promise for secure identification of suspects, victims, and missing persons, as well as in disaster victim identification (DVI). Unlike fingerprints or DNA, which may be degraded or unavailable, iris-based methods provide a non-invasive and highly accurate alternative with strong potential for forensic application.

Technological progress has accelerated this field, particularly with the introduction of artificial intelligence and deep learning-based algorithms. These approaches demonstrate resilience against common forensic challenges such as off-angle images, partial occlusions, and poor lighting. Multimodal biometric systems—integrating iris data with retina, sclera, or periocular features—offer further robustness. Advanced imaging modalities such as Optical Coherence Tomography Angiography (OCTA) not only strengthen anti-spoofing measures but also enable exploration of health-related biomarkers, including diabetic risk prediction, thereby expanding medico-legal applications.

Despite its promise, critical limitations persist. The post-mortem usability of the iris remains confined to a short time window, while lack of standardized collection protocols, forensic-specific validation studies, and precedent-setting case law impede broader acceptance. Ethical and legal concerns—ranging from privacy and consent to admissibility under Daubert and Frye standards—further complicate its forensic deployment.

Future directions demand interdisciplinary collaboration to establish standard operating procedures, validation frameworks, and ethical safeguards. By addressing these challenges, iris biometrics can evolve from a supportive tool to a scientifically validated, court-admissible pillar of forensic identification.

Keywords: Iris biometrics, Forensic, Post-mortem identification, Artificial intelligence

Introduction

The evolution of biometric modalities has profoundly transformed identity verification systems, with particularly significant implications for forensic science. Among the various modalities, iris biometrics has emerged as a front-runner owing to its unique physiological architecture, exceptional distinctiveness, high entropy, and relative stability throughout an individual's lifespan. Unlike fingerprints or

facial features, the iris remains largely unaffected by aging, external environmental factors, or superficial injuries, making it an especially reliable marker in forensic contexts.

A recent systematic review [1] has provided a critical baseline by cataloguing existing applications and limitations of iris-based recognition. However, the rapidly advancing landscape of both ophthalmic imaging and forensic informatics necessitates a broader and more nuanced exploration.

This commentary seeks to extend the dialogue by not only synthesizing ongoing research but also critically analyzing gaps that remain unaddressed. Specifically, it aims to emphasize:

Emerging developments in iris recognition technologies, such as advanced imaging techniques, deep learning–based pattern recognition, and multimodal integration with other biometric traits. Current forensic implementations, including casework examples, law enforcement databases, and security systems where iris biometrics have been practically deployed.

Ophthalmology-driven innovations such as Optical Coherence Tomography Angiography (OCTA), which offers unprecedented visualization of iris microvasculature, and EphA/Ephrin molecular pathways, which may in the future inform forensic differentiation at the cellular or genetic level.

Ethical and legal dilemmas, particularly regarding privacy, consent, data storage, potential misuse of biometric information, and the risk of surveillance overreach. Interdisciplinary integration prospects, bridging ophthalmology, forensic science, computer vision, artificial intelligence, and ethics, to establish a holistic approach toward identity verification and human rights safeguards.

By weaving together technological progress, forensic applicability, and bioethical considerations, this commentary underscores the dual reality of iris biometrics: an evolving promise on one hand, and persistent hurdles on the other. It also outlines possible future directions, from standardizing forensic protocols to enhancing accuracy under challenging conditions (e.g., post-mortem recognition, diseased eyes, or obscured imaging). In doing so, the discussion aspires to move beyond the descriptive cataloguing of iris biometrics toward a critical, interdisciplinary roadmap for its responsible and effective integration into forensic science.

Reevaluating Iris Pattern Stability in Forensic Contexts

The reliability of iris recognition rests on its exceptional stability and uniqueness, positioning it as a strong candidate for lifelong identification. The original review [1] highlighted this advantage, particularly when contrasted with more variable modalities such as fingerprints or facial recognition. Yet, emerging research has begun to question the assumption of absolute permanence, pointing to the influence of ocular pathologies—such as cataract, iritis, or abnormalities in pupillary dynamics—on recognition accuracy. These findings underscore the need for forensic practitioners to account for biological variability, particularly in cases involving deceased or injured individuals where iris texture may be partially degraded.

Equally important, longitudinal investigations into how iris patterns evolve with aging, trauma, or post-mortem changes remain limited within forensic literature. Such studies are essential for evaluating the temporal reliability of iris biometrics, especially in judicial contexts where identity verification must withstand the highest evidentiary standards.

OCTA in Forensic Iris Biometrics: Anti-spoofing and Temporal Stability

One of the pressing challenges in iris biometrics, particularly within forensic applications, is the vulnerability of conventional systems to spoofing attacks. Techniques such as high-resolution printed iris images, patterned contact lenses, or even prosthetic eyes can sometimes bypass texture-based recognition algorithms. This poses significant risks when iris evidence is expected to meet stringent legal and evidentiary standards.

Optical Coherence Tomography Angiography (OCTA) offers a promising solution. Unlike traditional surface imaging, OCTA enables the visualization of the iris microvasculature, providing a three-dimensional, physiologically anchored biometric signature [2]. Since vascular networks are unique to each individual and inherently tied to biological viability, OCTA introduces an additional layer of liveness detection that is exceedingly difficult to replicate artificially. This makes iris spoofing through printed media or synthetic devices far less feasible. From a forensic standpoint, OCTA integration enhances both precision and robustness. Not only can it strengthen identity verification in living individuals, but it also holds potential in post-mortem scenarios, where conventional iris texture may degrade due to corneal clouding or decomposition. Preliminary evidence suggests that microvascular patterns may remain detectable within a certain post-mortem interval, thereby extending the window of forensic utility. Furthermore, longitudinal monitoring of OCTA-derived vascular features could illuminate how iris microcirculation changes with aging, ocular disease, trauma, or death. These insights are vital for evaluating the temporal stability of iris recognition and for developing standardized forensic protocols that can withstand legal scrutiny. In sum, integrating OCTA into iris biometrics marks an important step toward next-generation forensic identification systems, combining structural texture analysis with vascular imaging to achieve higher resilience, accuracy, and evidentiary reliability.

Evolving Iris Recognition: AI Advances and Multimodal Approaches

Recent years have witnessed a significant transformation in iris recognition, largely driven by the advent of artificial intelligence and deep learning architectures. Models based on convolutional neural networks (CNNs) have surpassed traditional Daugman-inspired algorithms [3], demonstrating

improved resilience against common forensic challenges such as eyelid occlusions, motion blur, variable lighting, and off-angle image acquisition. These advancements have broadened the scope of iris recognition from controlled environments to more complex, real-world forensic contexts. At the same time, the emergence of multimodal biometric systems has further enhanced identification reliability. By combining complementary traits—such as iris texture, retinal patterns, scleral vasculature, and periocular morphology—these systems introduce redundancy that proves particularly valuable when a single modality is degraded, incomplete, or unavailable. In forensic casework, such multimodal integration offers a more robust safeguard against data loss or quality issues, thereby strengthening evidentiary reliability.

Despite their promise, these innovations raise critical challenges. The integration of multiple modalities demands data harmonization, cross-sensor interoperability, and increased computational resources. Furthermore, the reliance on black-box AI models poses concerns for transparency and legal admissibility. Without explainability and standardized forensic validation, courts may remain hesitant to accept AI-driven biometric evidence. In this evolving landscape, AI-powered iris recognition and multimodal fusion stand as pivotal advances with the potential to redefine forensic identification. Yet, their long-term impact depends on addressing issues of standardization, computational feasibility, and legal defensibility, ensuring that technological sophistication translates into practical, court-admissible forensic tools.

Forensic Applications: Expanding Use-cases

Although border control, immigration, and national ID systems have embraced iris recognition at scale, its penetration into core forensic domains—including crime scene analysis, disaster victim identification (DVI), and missing persons databases—remains comparatively limited. Nonetheless, pilot programs in countries such as India, the UAE, and the Netherlands demonstrate the potential of iris biometrics to enhance forensic workflows. When linked to large-scale identity infrastructures, such as Aadhaar-like systems or correctional facility databases, iris data can accelerate post-arrest identification, strengthen inter-agency collaborations, and reduce reliance on slower, less precise modalities.

Yet a major bottleneck persists: the absence of universally accepted forensic protocols. Unlike fingerprints, which benefit from the FBI's IAFIS/NGI standards and decades of jurisprudential acceptance, iris biometrics still lack standard operating procedures (SOPs) for image acquisition, quality benchmarking, and inter-laboratory reproducibility. This lack of formalization raises questions of evidentiary reliability and legal admissibility, particularly in jurisdictions where courts demand rigorously validated forensic methods. Encouragingly,

international standardization efforts—notably the ISO/IEC 19794-6 framework for iris image data interchange—provide a promising foundation. However, widespread adoption requires capacity building, forensic training programs, and integration into operational workflows. Without such harmonization, iris recognition risks remaining underutilized in forensic casework despite its strong scientific potential [4]. Ultimately, the expansion of forensic use-cases hinges not only on technological readiness but also on legal recognition, standardized procedures, and international collaboration, ensuring that iris biometrics achieves the same level of trust and evidentiary weight as fingerprints or DNA profiling.

Post-mortem Iris Recognition: Realistic or Theoretical

Trokielewicz *et al.* (2019) [5] highlighted the post-mortem usability of the iris, an area of growing forensic significance. Empirical evidence suggests that, under controlled conditions, the iris can retain recognizable features for approximately 6–12 hours after death [3]. Beyond this interval, however, a range of biological changes—such as pupil dilation, corneal opacity, intraocular pressure loss, and progressive tissue degradation—begin to compromise image quality and recognition accuracy. To address these limitations, experimental studies have employed near-infrared (NIR) imaging to penetrate corneal clouding and extend the viable post-mortem interval. While such approaches have shown promise in laboratory settings, their real-world applicability remains constrained by factors such as inconsistent ambient conditions, variable death-to-discovery intervals, and technical challenges in field deployment.

Practical hurdles also include natural eye closure after death, rigor mortis affecting eyelid manipulation, and taphonomy processes that accelerate ocular decomposition. These challenges underscore the necessity for standardized protocols and scientifically validated time windows during which iris recognition remains viable in post-mortem contexts. Moving forward, collaboration between forensic pathologists, biometric engineers, and ophthalmic specialists will be essential in developing post-mortem interval (PMI)-based usability metrics. Such guidelines could help determine when iris imaging is feasible in mortuary, disaster victim identification (DVI), or crime scene conditions, and when alternative modalities (e.g., dental records, DNA, or fingerprints) must be prioritized. Establishing these standards will be pivotal in elevating the iris from an experimental post-mortem modality to a practical and admissible forensic tool.

Privacy, Ethics, and Legal Admissibility

An often-overlooked dimension of iris biometrics lies in its ethical and legal implications. Since iris patterns can be captured remotely without consent, concerns around privacy,

surveillance overreach, and potential misuse are especially pressing. In forensic settings involving minors, victims, or vulnerable populations, strict protocols for informed consent, data protection, and chain of custody are essential.

In court, admissibility is guided by standards such as Frye, which emphasizes community acceptance, and Daubert, which focuses on scientific reliability and validation. While iris biometrics demonstrates strong scientific potential, it still lacks forensic-specific validation studies, standardized collection protocols, and precedent-setting case law. These are urgently needed to strengthen admissibility and ensure that iris evidence transitions from being viewed as experimental to becoming a recognized and reliable component of forensic science.

Future Prospects: Toward Explainable Iris Biometrics with OCTA Integration

The future of iris biometrics lies not only in improving accuracy but also in enhancing explainability and robustness. A key direction is the integration of Optical Coherence Tomography Angiography (OCTA), which allows visualization of the iris microvasculature. Unlike texture-based iris recognition alone, OCTA provides a deeper vascular signature that is far harder to spoof.

By combining surface texture analysis with vascular mapping, forensic systems could achieve multimodal confirmation, significantly reducing the risk of presentation (spoofing) attacks. Moreover, explainability improves because vascular patterns offer a biologically grounded rationale for identification, strengthening both forensic reliability and courtroom admissibility.

In the longer term, integrating OCTA-based data into AI models could also support health-risk predictions (e.g., early detection of diabetic microvascular changes), broadening the forensic-medical interface.

Conclusion

Iris biometrics represents a powerful yet underutilized tool in forensic science, with strong potential in secure identification, victim verification, and biometric intelligence. However, its transition from experimental to mainstream forensic practice requires overcoming substantial technical, legal, and ethical barriers. Standardized protocols for data acquisition and validation, interdisciplinary collaboration between forensic scientists, ophthalmologists, and biometric engineers, and stronger ethical frameworks are essential for responsible adoption.

Looking ahead, the forensic community must prioritize research in post-mortem iris usability, integration of

explainable AI, incorporation of advanced imaging modalities such as OCTA, and the establishment of precedent-setting legal validations. Only through such collective efforts can iris recognition evolve from auxiliary evidence into a primary, court-admissible forensic modality.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors have consented to the publication of this manuscript.

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