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Review Article:
The Efficacy and Implementation of Artificial Intelligence in Crime Scene Investigation: A Systematic Review of Meta-Analyses

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Abstract

Background: Artificial Intelligence (AI) is rapidly transforming forensic science, offering new paradigms for evidence analysis and victim identification. A synthesis of high-level evidence is required to guide its integration into routine forensic practice.

Aims: This systematic review aims to consolidate findings from existing meta-analyses to evaluate the performance, implementation requirements, and limitations of AI applications specifically within crime scene investigation contexts.

Materials and Methods: We conducted a systematic search using the Elicit engine, screening 498 papers against stringent criteria focusing on quantitative effectiveness, rigorous study design, and direct relevance to crime scene investigation. Data from four included meta-analyses (encompassing 32-39 primary studies each) were extracted and synthesized.

Results: AI applications demonstrated high efficacy across diverse forensic domains. In forensic odontology, AI algorithms for dental identification and age estimation surpassed traditional methods, while gender determination from orthopantomograms achieved a pooled accuracy of 88.66% (up to 99.20% in individual studies). Computed Tomography (CT) for death investigation provided accuracy comparable to autopsy, serving as a vital non-invasive alternative. Crime pattern analysis effectively utilized machine learning to identify spatial-temporal trends in government data. Critical success factors identified include the necessity for high-quality, diverse training data, substantial hardware investment (e.g., CT scanners >$80,000), and the need for standardized protocols and specialist training.

Conclusion: AI holds significant promise for enhancing the accuracy and efficiency of forensic investigations. However, its successful implementation is contingent upon overcoming challenges related to data bias, cost, and the need for robust regulatory frameworks and expert oversight. Future work must prioritize standardized validation studies and interdisciplinary

collaboration between forensic experts and data scientists.

Keywords: Artificial Intelligence, Forensic Medicine, Crime Scene Investigation, Systematic Review, Meta-Analysis, Machine Learning, Postmortem CT, Forensic Odontology.

Introduction: The landscape of crime scene investigation (CSI) is being reshaped by the advent of Artificial Intelligence (AI). Tasks ranging from victim identification and cause of death determination to complex pattern analysis of criminal incidents are now being augmented by machine learning algorithms and advanced imaging technologies. While primary studies highlight the potential of these tools, a consolidated, high-level evidence base is crucial for forensic practitioners and policymakers to make informed decisions regarding their adoption.

The Journal of the Indian Academy of Forensic Medicine has a vested interest in the critical appraisal of emerging technologies that impact medicolegal death investigation and forensic practice. This systematic review of meta-analyses seeks to provide a comprehensive overview of the current evidence, moving beyond individual studies to synthesize broader trends. It specifically evaluates the quantitative effectiveness, practical implementation considerations, and overarching limitations of AI applications within the unique demands of the crime scene and subsequent forensic laboratory analysis.

Materials and Methods

2.1. Search Strategy and Screening

A semantic search was performed using the query "Effective use of AI Applications in Crime Scene Investigation: Meta-Analysis" across the Elicit search engine, which indexes over 138 million academic papers from sources including Semantic Scholar and OpenAlex. The initial search yielded 498 relevant papers.

2.2. Inclusion and Exclusion Criteria

Papers were screened holistically based on the following criteria:

- **Focus:** AI applications specifically within crime scene investigation or direct forensic analysis of evidence therefrom.
- **Study Design:** Systematic reviews or meta-analyses synthesizing empirical data.

- **Data:** Reporting of quantitative performance metrics (e.g., accuracy, sensitivity, specificity).
- **Context:** Analysis based on real-world forensic data, simulated crime scenes, or controlled forensic scenarios.

2.3. Data Extraction

A structured data extraction protocol was employed to collect information on:

- AI technologies and algorithms used.
- Specific forensic application and investigation stage.
- Reported performance metrics and comparative effectiveness.
- Study design and dataset characteristics.
- Implementation context, including cost and training requirements.
- Key findings, limitations, and identified research gaps.

Results: Four meta-analyses, published between 2020 and 2025, met the inclusion criteria. The characteristics of these studies are summarized in Table 1.

Table 1: Characteristics of Included Meta-Analyses

Please refer to Table 1 here

3.1. Forensic Identification Through Dental Analysis

Two studies focused on AI in forensic odontology. Khan et al. demonstrated that AI algorithms automated dental charting and age estimation with superior accuracy compared to conventional methods. Dashti et al. specifically evaluated gender determination from orthopantomograms (OPGs), reporting a pooled accuracy of 88.66%, with individual models achieving up to 99.20% accuracy. The models showed high specificity, though sensitivity varied, indicating performance is dataset-dependent.

3.2. Radiographic Death Investigation

The Eames et al. meta-analysis found that postmortem CT scanning achieved diagnostic accuracy closely matching traditional autopsy, particularly in identifying bone fractures and pathologies. It was highlighted as a valuable non-invasive alternative in cases where autopsy is refused for religious reasons or is infeasible due to advanced decomposition. Limitations included poor soft-tissue assessment and artifacts from dental work.

3.3. Crime Pattern Analysis

Prado et al. reviewed the use of machine learning (e.g., K-Means, K-Nearest Neighbors) on government open data for criminal incident analysis.

These systems were effective in uncovering spatio-temporal crime patterns to aid in investigation and prediction, though the limited number of studies suitable for meta-analysis indicated challenges in data availability and standardization.

3.4. Performance and Implementation Considerations

AI consistently demonstrated high performance, often exceeding traditional methods in speed and precision. However, implementation requires significant investment, both financially (e.g., CT scanners costing >$80,000) and in human resources, necessitating technically trained specialists and standardized training protocols. Integration into existing workflows, such as using CT as an autopsy supplement or AI for automated dental records analysis, was a key success factor.

Discussion: This review synthesizes evidence that AI is a powerful tool with demonstrable benefits in forensic science. The high accuracy in tasks like dental identification and gender determination underscores its potential to reduce human error and expedite investigations. The role of CT as a viable alternative to autopsy is particularly significant for forensic medicine in multicultural contexts like India, where religious objections to autopsy are common.

However, the path to routine adoption is fraught with challenges. The **"garbage in, garbage out"** principle is paramount; AI performance is critically dependent on high-quality, diverse, and unbiased training data. The variability in model sensitivity reported by Dashti et al. is a direct consequence of this dependency. Furthermore, the high cost of technology and the need for specialized training create significant barriers, especially in resource-constrained settings.

A critical discussion point is the **indispensable role of human oversight**. AI should be viewed as a decision-support tool, not a replacement for the forensic expert. Validation of AI-generated results by qualified forensic pathologists and odontologists remains essential to ensure legal admissibility and maintain the chain of custody.

4.1. Implications for Forensic Medicine

- **Practice:** Forensic units should consider pilot projects for specific AI applications (e.g., dental age estimation) while prioritizing the development of internal validation protocols.
- **Training:** Forensic medicine curricula must incorporate modules on digital evidence, AI fundamentals, and the interpretation of AI-assisted results.
- **Policy:** National forensic bodies need to establish standardized guidelines for the use of AI, addressing data privacy, algorithmic transparency, and ethical concerns to prevent misuse and bias.

4.2. Limitations of the Review

This study is limited by its reliance on secondary research (meta-analyses). The findings are also constrained by the scope and quality of the included meta-analyses, two of which were accessed only as abstracts.

Conclusion: Artificial Intelligence presents a transformative opportunity for crime scene investigation and forensic medicine, offering enhanced accuracy, efficiency, and novel analytical capabilities. Its successful integration, however, hinges on a balanced approach that recognizes its technical limitations and implementation challenges. Future efforts must be directed towards creating robust, standardized, and transparent AI systems through sustained collaboration between forensic scientists, medicolegal experts, and AI developers. Proactive policy-making and continuous professional development are essential to harness the full potential of AI while upholding the highest standards of forensic practice.

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Table 1: Characteristics of Included Meta-Analyses

Study	**Primary Studies Analyzed**	**Forensic Application**	**AI Technologies Used**
Khan et al., 2024	32	Victim ID & Age Estimation (Dental)	Machine Learning (K Vaal, Cameriere methods)
Eames et al., 2020	39	Victim ID & Cause of Death (CT)	Computed Tomography (Advanced Imaging)
Prado et al., 2020	3 (for meta-analysis)	Crime Pattern Analysis	K-Means, K-NN, Apriori, Decision Tree, SVM, etc.
Dashti et al., 2025	13	Gender Determination (Dental Radiographs)	AI Image Analysis Algorithms