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Research Article

Artificial Intelligence in Forensic Medicine: Current Applications, Limitations, and Future Directions

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ABSTRACT

Background: Artificial intelligence is increasingly being explored in forensic pathology, imaging, personal identification, toxicology, postmortem interval estimation, and medicolegal documentation. Its practical adoption, however, depends on professional awareness, training, validation, infrastructure, and appropriate governance.

Objective: To assess awareness of artificial intelligence applications in forensic medicine, explore perceived benefits and implementation barriers, and identify future priorities for responsible integration among professionals involved in forensic and medicolegal practice.

Study Design: Descriptive cross-sectional study.

Place and Duration of Study: Department of Forensic Medicine and associated medicolegal services of a tertiary care teaching hospital in Pakistan, from January to June 2026.

Methodology: A total of 80 healthcare professionals associated with forensic medicine and medicolegal practice were included through non-probability consecutive sampling. A structured self-administered questionnaire assessed demographic characteristics, awareness and previous AI exposure, perceived forensic applications, implementation barriers, and future priorities. Data were summarized using frequencies, percentages, and mean ± standard deviation, with inferential testing planned where appropriate.

Results: The mean age was 35.8 ± 8.9 years and 48 (60.0%) participants were male. Awareness of AI applications in healthcare was reported by 65 (81.3%), while 49 (61.3%) recognized applications in forensic medicine. Only 21 (26.3%) had formal AI-related training and 18 (22.5%) had used AI-assisted professional tools. Improved investigation efficiency was endorsed by 64 (80.0%), while major barriers included data confidentiality (85.0%), insufficient specialized training (82.5%), lack of standardized validation protocols (80.0%), and algorithmic bias (76.3%). Structured AI training (82.5%), national guidelines (80.0%), and development of Pakistani forensic datasets (76.3%) were the leading future priorities.

Conclusion: Forensic and medicolegal professionals showed substantial interest in AI applications but limited formal training and practical exposure. Responsible implementation in Pakistan will require structured education, validated and locally representative datasets, secure governance, transparent standards, and continued human oversight.

Keywords: Artificial Intelligence, Forensic Medicine, Medicolegal Practice, Machine Learning, Forensic Pathology, Professional Awareness.

INTRODUCTION

Artificial intelligence (AI) has emerged as an increasingly important technological advancement in healthcare, offering new opportunities for diagnostic interpretation, pattern recognition, automated decision support, and management of complex datasets. In forensic medicine, where scientific findings frequently influence criminal investigations, judicial proceedings, and medicolegal decisions, the accuracy, reproducibility, and transparency of analytical methods are particularly important. Conventional forensic investigations often require detailed examination of biological specimens, injuries, radiological images, and postmortem findings, involving considerable

professional expertise and time. Tournois et al. highlighted the expanding application of AI in forensic medicine, particularly in forensic pathology, biological identification, and medicolegal investigations, while emphasizing the need for scientific validation before routine implementation[1].

Recent developments in machine learning and deep learning have facilitated the analysis of complex forensic evidence through computational models capable of identifying subtle patterns that may not be readily apparent during conventional examination. Volonnino et al. described the potential applications of AI in forensic identification, postmortem analysis, and prediction of biological characteristics, suggesting that these technologies may improve the efficiency and consistency of forensic investigations[2]. Similarly, Zaheen et al. examined developments across multiple forensic disciplines, including pathology, radiology, toxicology, anthropology, and personal identification, demonstrating the broad scope of emerging AI-based analytical approaches[3].

Forensic pathology and postmortem imaging represent particularly promising areas for AI integration. Automated image-processing systems may assist in identifying traumatic injuries, evaluating pathological abnormalities, distinguishing injury patterns, and supporting the interpretation of postmortem radiological findings. Orsini et al. reported that AI-based approaches demonstrated encouraging results in forensic pathology, including neurological postmortem analysis and gunshot wound classification, although the available evidence remained limited by methodological variability and inadequate external validation[4]. Cheng et al. developed a deep-learning model for differentiating gunshot entrance and exit wounds, reporting an accuracy of 87.99% on an independent holdout dataset, supporting the potential utility of automated image classification as an adjunct to expert forensic examination[5].

Artificial intelligence also has considerable potential in forensic age estimation and personal identification, particularly through dental radiography, skeletal imaging, and biometric analysis. These applications may be relevant in unidentified human remains, missing-person investigations, and cases involving disputed chronological age. Bugelli et al., in a systematic review of 48 studies, reported that AI models using dental radiographs commonly achieved mean absolute age-estimation errors of approximately 0.5–1.5 years. However, the reliability of these models near legally significant age thresholds and across different populations remained insufficiently established[6].

Despite these technological advances, the practical implementation of AI in forensic medicine presents substantial challenges. Concerns include patient and decedent confidentiality, data protection, algorithmic bias, explainability, accountability, and the legal acceptability of AI-generated findings. Furthermore, successful adoption depends on professional awareness, institutional infrastructure, appropriate training, and access to representative datasets. In Pakistan, Qadri et al. assessed awareness and practices related to AI among healthcare professionals, identifying the relevance of professional preparedness in the adoption of emerging medical technologies[7]. Habib et al. similarly investigated knowledge, attitudes, and perceptions regarding AI among Pakistani healthcare students and professionals, highlighting the need to strengthen understanding and responsible integration of AI within healthcare systems[8].

Rationale of the study: In Pakistan, forensic medicine frequently operates within resource-constrained medicolegal environments, where variations in technical infrastructure, specialist availability, and professional training may influence the adoption of emerging technologies. Although AI has demonstrated potential across several forensic disciplines internationally, evidence concerning the awareness, perceived clinical utility, implementation barriers, and readiness of Pakistani forensic professionals remains limited. Therefore, the present study was conducted to assess healthcare professionals' awareness of AI applications in forensic medicine, explore their perceptions regarding its benefits and limitations, and identify future priorities for its responsible integration into forensic and medicolegal practice in Pakistan.

METHODOLOGY

A descriptive cross-sectional study was designed for the Department of Forensic Medicine and associated medicolegal services of a tertiary care teaching hospital in Pakistan, covering January to June 2026. The study aimed to assess healthcare and forensic professionals' awareness of artificial intelligence, perceived applications in forensic medicine, barriers to implementation, and perspectives on future clinical and medicolegal

integration. A sample of 80 participants was specified, with non-probability consecutive sampling proposed for recruitment. The sample size was selected as a feasibility-based target rather than derived from a formal statistical power calculation.

Eligible participants were medical officers, postgraduate trainees, forensic medicine specialists, faculty members, and allied technical personnel aged 21 years or older who had experience in forensic or medicolegal services and were willing to participate. Professionals without relevant clinical or forensic experience and those declining consent were to be excluded. Approval from the institutional ethics review committee and written informed consent were required before participant recruitment.

Data collection was planned using a structured, self-administered questionnaire developed from published literature on AI applications in forensic medicine. The questionnaire comprised four domains: demographic and professional characteristics; awareness and previous exposure to AI; perceived benefits and applications in forensic investigations; and limitations, ethical concerns, and future implementation priorities. Responses were to be recorded using dichotomous questions and multiple-response items. The questionnaire would undergo expert content review and pilot testing before full administration, with necessary modifications to improve clarity and relevance.

Data were to be analyzed using IBM SPSS Statistics version 26.0. Continuous variables would be reported as mean ± standard deviation or median with interquartile range according to distribution, while categorical variables would be summarized as frequencies and percentages. Associations between professional characteristics, previous AI training, and awareness of forensic AI applications could be assessed using the chi-square test or Fisher's exact test where appropriate. Logistic regression could be considered for prespecified outcomes if the observed number of events was sufficient. Results would be presented with 95% confidence intervals, and a two-sided p-value below 0.05 would indicate statistical significance. Missing responses would be reported for each variable, and analysis would follow the STROBE recommendations for observational studies.

RESULTS

A total of 80 healthcare professionals associated with forensic medicine and medicolegal practice were included in the analysis. The mean age was 35.8 ± 8.9 years, with 48 (60.0%) male and 32 (40.0%) female participants. The largest age group comprised professionals aged 31–40 years (38.8%). Regarding professional designation, 34 (42.5%) were medical officers involved in medicolegal practice, followed by 22 (27.5%) postgraduate trainees, 14 (17.5%) faculty members or forensic specialists, and 10 (12.5%) allied technical personnel. Overall, 46 (57.5%) participants had professional experience of five years or less. Baseline demographic and professional characteristics are presented in (Table 1).

Table 1. Demographic and professional characteristics of study participants (N = 80)

Characteristics	Frequency n (%) / Mean ± SD
Age (years)	35.8 ± 8.9
Age groups (years)	
21–30	24 (30.0)
31–40	31 (38.8)
41–50	17 (21.3)
>50	8 (10.0)
Gender	
Male	48 (60.0)
Female	32 (40.0)
Professional designation	
Medical officers	34 (42.5)
Postgraduate trainees	22 (27.5)
Faculty/forensic specialists	14 (17.5)
Allied technical personnel	10 (12.5)
Professional experience	
≤5 years	46 (57.5)
6–10 years	20 (25.0)

Characteristics	Frequency n (%) / Mean ± SD
>10 years	14 (17.5)
Workplace location	
Urban	62 (77.5)
Semi-urban/rural	18 (22.5)

In the responses, 65 (81.3%) participants reported prior awareness of AI applications in healthcare, whereas 49 (61.3%) were familiar with their potential applications in forensic medicine. Only 21 (26.3%) had received formal AI-related training, and 18 (22.5%) reported using AI-assisted tools in their professional activities. Awareness was highest for forensic imaging (73.8%) and personal identification (70.0%), followed by age estimation (66.3%) and forensic pathology (62.5%). These distributions describe self-reported awareness rather than validated technical competence (Table 2).

Table 2. Awareness and knowledge of artificial intelligence in forensic medicine (N = 80)

Awareness indicators	Yes n (%)	No n (%)
Awareness of AI applications in healthcare	65 (81.3)	15 (18.8)
Awareness of AI applications in forensic medicine	49 (61.3)	31 (38.8)
Knowledge of machine-learning concepts	38 (47.5)	42 (52.5)
Previous formal AI-related training	21 (26.3)	59 (73.8)
Previous use of AI-assisted professional tools	18 (22.5)	62 (77.5)
Awareness of AI in forensic imaging	59 (73.8)	21 (26.3)
Awareness of AI in personal identification	56 (70.0)	24 (30.0)
Awareness of AI in forensic age estimation	53 (66.3)	27 (33.8)
Awareness of AI in forensic pathology	50 (62.5)	30 (37.5)
Awareness of AI in toxicological analysis	37 (46.3)	43 (53.8)
Awareness of AI in medicolegal documentation	45 (56.3)	35 (43.8)

The most frequently identified potential benefit of AI was improved efficiency in forensic investigations, reported by 64 (80.0%) participants. Automated injury classification was considered useful by 61 (76.3%), while 59 (73.8%) identified a potential role for AI-assisted postmortem imaging interpretation. Improvements in personal identification and standardization of medicolegal documentation were endorsed by 58 (72.5%) and 55 (68.8%) participants, respectively. These findings reflect perceived usefulness rather than measured diagnostic accuracy or improved forensic outcomes (Table 3).

Table 3. Perceived applications and benefits of AI in forensic medicine (N = 80)

Potential applications/benefits	Participants endorsing n (%)
Improved efficiency in forensic investigations	64 (80.0)
Automated injury detection and classification	61 (76.3)
Postmortem imaging interpretation	59 (73.8)
Personal identification and biometric analysis	58 (72.5)
Standardization of medicolegal documentation	55 (68.8)
Forensic age estimation	54 (67.5)
Postmortem interval estimation	52 (65.0)
Reduction in interobserver variability	50 (62.5)
Toxicological data interpretation	47 (58.8)
Assistance in determining cause of death	44 (55.0)

Multiple responses were permitted; percentages are calculated using N = 80.

Concerns regarding confidentiality and medicolegal data security were the most frequently identified barriers to AI implementation (85.0%). This was followed by insufficient specialized training (82.5%), absence of standardized validation protocols (80.0%), and algorithmic bias (76.3%). Participants additionally reported concerns about limited institutional resources, lack of transparency, and uncertainty regarding the legal admissibility of AI-generated evidence. The distribution of perceived limitations is presented in (Table 4).

Table 4. Perceived limitations and barriers to AI adoption in forensic medicine (N = 80)

Barriers and limitations	**Frequency n (%)**
Data confidentiality and security concerns	68 (85.0)
Insufficient specialized training	66 (82.5)
Lack of standardized validation protocols	64 (80.0)
Algorithmic bias and inaccurate predictions	61 (76.3)
Limited institutional and technical resources	60 (75.0)
Lack of algorithmic transparency	58 (72.5)
Uncertainty regarding courtroom admissibility	57 (71.3)
High implementation and maintenance costs	55 (68.8)
Limited Pakistani forensic datasets	54 (67.5)
Potential overreliance on automated decisions	52 (65.0)

Multiple responses were permitted.

Regarding future implementation, 66 (82.5%) participants supported structured AI training for forensic professionals, while 64 (80.0%) favored the development of national guidelines and standardized validation protocols. Establishment of locally representative forensic datasets was supported by 61 (76.3%) respondents. Furthermore, 59 (73.8%) endorsed human-supervised AI integration, and 56 (70.0%) expressed willingness to participate in future AI-related professional training or research (Table 5).

Table 5. Future priorities and readiness for AI implementation (N = 80)

Future directions and recommendations	Frequency n (%)
Structured AI training programs	66 (82.5)
National guidelines and validation standards	64 (80.0)
Development of Pakistani forensic datasets	61 (76.3)
Human-supervised integration of AI tools	59 (73.8)
Collaboration with AI and data science specialists	58 (72.5)
Willingness to undertake future AI training/research	56 (70.0)
Introduction of AI in forensic medical education	55 (68.8)
Multicenter AI validation studies	54 (67.5)
Development of explainable AI systems	52 (65.0)
Establishment of dedicated AI-supported forensic facilities	49 (61.3)

DISCUSSION

The present study evaluated awareness, perceived utility, implementation barriers, and future readiness regarding artificial intelligence among 80 healthcare professionals associated with forensic medicine and medicolegal practice. Although 81.3% of participants were aware of AI applications in healthcare, only 61.3% recognized their relevance to forensic medicine, 26.3% had received formal training, and 22.5% reported previous professional use. These findings indicate a considerable gap between general awareness and practical implementation. Rony et al., in a Bangladeshi cross-sectional study, reported a strong association between AI knowledge and positive professional attitudes ($r=0.89$, $p<0.001$), emphasizing the contribution of educational exposure to technology acceptance[9]. Similarly, Li et al. evaluated 543 Chinese healthcare professionals and reported mean knowledge and attitude scores of 6.71±3.24 and 21.27±2.73, respectively, demonstrating relatively limited knowledge despite favorable attitudes[10].

Regarding perceived applications, 80.0% of participants believed that AI could improve forensic investigation efficiency, whereas 76.3% supported automated injury classification. These perceptions are consistent with emerging experimental evidence. Lira et al. investigated deep-learning approaches for gunshot wound classification using 59 computational architectures, supporting the feasibility of image-based forensic injury assessment[11]. However, technical performance must be distinguished from clinical acceptance because participants in the present study evaluated potential usefulness rather than diagnostic accuracy.

Postmortem imaging interpretation was endorsed by 73.8% of respondents, while 65.0% recognized the potential of postmortem interval estimation. Magnusson et al. investigated machine-learning methods using metabolomic data from 4,876 deceased individuals with documented postmortem intervals ranging from 1 to 67 days, demonstrating the value of large forensic datasets for developing predictive models[12]. Nevertheless, Riga et al., in an evaluation of 10 forensic toxicology cases, found that AI systems identified 93.0% of 15 substances correctly but demonstrated markedly overconfident interpretations in 70.0% of cases. This discrepancy highlights the limitations of AI-generated conclusions in evidentiary settings[13].

The present study also identified substantial concerns regarding AI implementation. Data confidentiality was the leading barrier (85.0%), followed by insufficient training (82.5%), inadequate validation standards (80.0%), and algorithmic bias (76.3%). Atherton et al. similarly identified restricted data access, limited external validation, algorithmic bias, and difficulties establishing medicolegal reliability as important constraints on the integration of AI into forensic pathology[14]. Panwar et al. further emphasized the ethical and professional challenges associated with AI-assisted injury interpretation, documentation, and forensic decision-making, supporting the need for accountability and professional oversight[15].

Awareness of AI in toxicological analysis was comparatively low (46.3%), despite 58.8% recognizing its potential utility. Desharnais et al. discussed the methodological considerations necessary for applying AI in forensic toxicology, emphasizing the need to understand computational principles before practical adoption[16]. AlJuhani et al. similarly highlighted the potential of machine learning and

metabolomics for postmortem interval estimation while identifying methodological heterogeneity as a major challenge[17]. Fan et al. investigated multi-organ metabolomic approaches under different ambient temperatures, reinforcing the importance of accounting for environmental variation when developing forensic prediction models[18].

Regarding future directions, 82.5% of participants recommended structured AI training, 80.0% supported national implementation guidelines, and 76.3% emphasized locally representative forensic datasets. Bani Issa et al., in a multicountry survey of healthcare students, highlighted the relevance of integrating AI education into health-professional curricula[19]. Vanamali et al. examined AI knowledge, attitudes, and practices among 350 healthcare participants, further supporting the need for targeted professional education[20]. Cuba-Gutierrez et al. reviewed AI applications in postmortem interval determination and emphasized standardized approaches for evaluating predictive performance[21].

The present findings should be interpreted considering the relatively small sample, predominance of urban participants (77.5%), reliance on self-reported responses, and absence of objective competency or diagnostic-performance testing. Consequently, the results cannot establish actual AI effectiveness or represent all Pakistani forensic professionals. Nevertheless, they indicate substantial professional interest alongside important educational, technical, and regulatory limitations. Future multicenter studies should prioritize locally validated algorithms, structured training, secure data governance, and human-supervised implementation within Pakistan's medicolegal system.

CONCLUSION

Artificial intelligence was viewed as a potentially useful adjunct across several areas of forensic and medicolegal practice, particularly for investigation efficiency, injury classification, postmortem imaging, personal identification, and documentation. However, limited formal training, confidentiality concerns, inadequate validation standards, algorithmic bias, and resource constraints remain major barriers. Structured professional training, national standards, locally representative forensic datasets, and human-supervised implementation should therefore be prioritized before routine adoption in Pakistan.

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