



A Scoping Review of Artificial Intelligence in Perioperative Anesthesia: Current Applications, Challenges, and Roadmap for the Future

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Abstract

Background: Artificial Intelligence (AI) is rapidly integrating into anesthesiology, with the potential to enhance patient safety and advance precision in the field of anesthesia. This scoping review synthesizes recent literature on AI applications across the perioperative care setting.

Methods: A focused review of PubMed, Google Scholar, and Research Rabbit identified 24 articles. The selection included a primary analysis group of 16 articles published in 2025, complemented by 8 earlier studies for context. Findings were thematically synthesized and categorized by perioperative phase: preoperative, intraoperative, and postoperative. AI-powered tools assisted in initial synthesis, followed by manual review and integration by the authors.

Results: The 2025 literature highlights AI's evolution from theoretical models to clinically relevant tools. Preoperatively, Deep Learning, including Convolutional Neural Networks (CNNs), enables accurate and noninvasive prediction of difficult airways, and comprehensive risk stratification using tools like the POTTER and MySurgeryRisk calculators. Intraoperatively, advanced hybrid models combining Long Short-Term Memory (LSTM), Transformer, and Kolmogorov Arnold Networks (KAN) are being developed for enhanced depth of anesthesia monitoring, while closed-loop systems are used to automate drug delivery. Postoperatively, Natural Language Processing (NLP) and predictive algorithms are utilized to optimize pain management and anticipate complications.

Conclusion: The current literature in advanced AI illustrates a clear progression from theoretical concepts to practical applications in anesthetic care. AI is poised to become an indispensable component of perioperative medicine, facilitating data-driven precision in the field of anesthesia. However, successful and equitable implementation will require addressing key challenges in data governance, model interpretability, and ethical oversight.

Keywords: Artificial Intelligence; Anesthesiology; Perioperative Care; Machine Learning; Deep Learning; Precision Anesthesia; Clinical Decision Support

Introduction

The integration of Artificial Intelligence (AI) into medicine holds immense potential to enhance diagnostic accuracy, personalize treatments, and streamline clinical workflows [1]. Anesthesiology, a data-intensive specialty, is uniquely positioned to benefit from these advancements [1]. The shift toward precision anesthesia marks a departure from population-

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based norms, enabling individualized care based on genetic, physiologic, and historical patient data [2]. Foundational research has highlighted key domains, including depth of anesthesia (DoA) monitoring, automated anesthetic control, risk prediction, and ultrasound guidance [3].

Systematic reviews have further categorized AI's clinical applicability into DoA monitoring, image-guided techniques, and adverse event prediction with artificial neural networks (ANNs) frequently employed [4]. These studies have established the potential for AI to facilitate a more predictive and preventive approach to anesthesia care [5]. Since 2018, bibliometric analyses have revealed growing interest in hypotension prediction and anesthetic depth monitoring [6]. This scoping review builds on that foundation by synthesizing the major innovations and applications reported in the 2025 literature.

Methods

A comprehensive literature review was conducted to identify current and emerging applications of AI in the clinical practice of anesthesiology. Systematic searches were performed across key databases, including PubMed and Google Scholar, and enhanced using AI-powered tools such as Research Rabbit and Google Gemini to uncover interconnected and relevant publications. The search strategy combined keywords including "AI," "anesthesia," "perioperative care," "algorithms," and "devices." The initial search was supplemented by a citation tracking and snowballing technique to identify interconnected and relevant publications, ensuring a thorough synthesis of the available evidence.

This scoping review incorporated 24 peer-reviewed articles, divided into two cohorts: a foundational group of 8 articles published prior to 2025 to establish context, and a primary analysis group of 16 articles published in 2025. Data from each article was systematically extracted, focusing on the specific AI algorithms and devices discussed and their application within the perioperative stages of anesthesia. Findings were categorized into three phases of care: preoperative, intraoperative, and postoperative, to enable a structured analysis of AI's evolving role in anesthetic practice. Table 1 provides a detailed summary of these AI applications categorized by perioperative phase.

AI in preoperative care: Proactive risk mitigation

The preoperative phase is crucial for identifying patient risks and planning for a safe anesthetic course. AI applications have demonstrated significant sophistication in enhancing these assessments. A primary focus has been on airway management, a cornerstone of anesthetic safety. While traditional airway assessment methods often lack precision, AI provides a more robust approach (Table 1). Systematic

reviews of current literature show that AI models, particularly those using Convolutional Neural Networks (CNNs) and other deep learning algorithms, excel at analyzing patient images (e.g., facial photographs, ultrasound) to accurately predict difficult airways [7,8]. These tools can automatically classify Mallampati scores, measure thyromental distance, and identify other subtle anatomical predictors of difficult intubation from images, providing clinicians with a noninvasive, rapid, and objective assessment tool [7]. The predictive power of these analyses extends to forecasting the likelihood of difficult ventilation and intubation.

Beyond airway assessment, AI models are being used for comprehensive risk stratification (Table 1). By analyzing electronic health records (EHRs), AI can predict the likelihood of various perioperative complications, such as postoperative nausea and vomiting (PONV), delirium, or acute kidney injury [9]. Specific AI tools like the POTTER (Postoperative Transfer to ICU Risk) calculator have demonstrated superior accuracy in predicting postoperative complications and mortality compared to traditional methods. Furthermore, real-time systems like MySurgeryRisk can be integrated directly into EHRs to support bedside clinical decision making, signaling a shift toward data-driven, precision surgical care [2]. AI is also beginning to assist in anesthesia planning itself, with models suggesting optimal drug choices and initial dosing based on a patient's specific physiological profile and surgical context [10].

AI in intraoperative care: Enhancing real-time decision making

The intraoperative phase is the most dynamic period of anesthesia care, requiring constant vigilance. AI is emerging as a powerful copilot for the anesthesiologist, enhancing monitoring, automating drug delivery, and providing real-time decision support.

Depth of anesthesia (DoA) and hemodynamic monitoring

AI continues to refine DoA monitoring (Table 1), moving beyond traditional electroencephalogram (EEG) based indices. A study by Wang et al. [11] introduced a novel hybrid AI model combining Long Short Term Memory (LSTM) networks, Transformer architectures, and Kolmogorov Arnold Networks (KAN). This sophisticated model predicts anesthesia depth not just from EEG signals but also from the drug infusion history itself, capturing complex temporal dependencies and nonlinear relationships. Concurrently, AI systems incorporating LSTM algorithms are being used to manage anesthetic dosage in real-time during complex procedures like cancer surgery, demonstrating the ability to maintain greater hemodynamic stability compared to manual control [12].

Table 1: Key applications of artificial intelligence (AI) across the perioperative period in anesthesiology.

AI Application	Function	AI/ML Component	Clinical Use/Notes
Preoperative Phase			
Difficult Airway Assessment	Analyzes patient facial photographs and ultrasound images to predict difficult intubation or ventilation noninvasively [7,8].	Deep Learning, specifically Convolutional Neural Networks (CNNs) [7,8,19,20].	Automatically classifies Mallampati scores and measures thyromental distance from images, providing rapid and objective risk assessment [7].
Comprehensive Risk Stratification	Predicts patient-specific risk for various postoperative complications, mortality, or ICU transfer by analyzing EHR data [2,9].	Predictive Models, Machine Learning Algorithms [1,9,15].	Examples include POTTER (POstoperative Transfer to ICU Risk) and MySurgeryRisk calculators, which integrate patient data for bedside decision support [2]. Predicts complications like PONV, delirium, and acute kidney injury [9].
Anesthetic Planning Support	Recommends optimal drug choices and initial dosing based on a patient's unique physiological profile and surgical context [10].	Machine Learning models such as Support Vector Machines (SVM), Decision Trees, and Gradient Boosting [10].	Moves toward data-driven precision anesthesia planning by forecasting specific anesthetic requirements before surgery [10].
Simulation and Training	Provides realistic training environments for managing complex anesthetic scenarios, particularly difficult airways [8,14].	Virtual Reality (VR), Augmented Reality (AR), and intelligent simulators [8,14].	Allows trainees to practice complex procedures and decision-making in a safe, controlled setting [8].
Intraoperative Phase			
Depth of Anesthesia (DoA) Monitoring	Provides real-time analysis and prediction of anesthetic depth by interpreting physiological signals like EEG [11,22].	Advanced hybrid models (e.g., LSTM, Transformer, KAN) [11], Artificial Neural Networks (ANNs), and Fuzzy Logic systems [3,4,22,24].	Models capture complex relationships between drug infusion history and EEG signals to provide a more reliable measure of consciousness than traditional indices [11].
Closed-Loop Anesthesia Delivery	Automates the titration of hypnotic and analgesic drugs to maintain hemodynamic stability and a consistent depth of anesthesia [13].	Reinforcement Learning, LSTM algorithms, and other Machine Learning models integrated into closed-loop feedback systems [3,12,13].	Systems demonstrate greater hemodynamic stability compared to manual control by continuously adapting drug delivery to the patient's state [12].
Hemodynamic Event Prediction	Tracks surgical progress and analyzes vital signs to anticipate and alert clinicians to impending hemodynamic instability, such as hypotension [6, 14].	Computer Vision (for surgical tracking) and Machine Learning algorithms (for prediction) [6,14].	Fosters surgical-anesthetic synergy by alerting the team to high-stimulation events, allowing for preemptive intervention [14].
Procedural Guidance	Assists clinicians with real-time image interpretation for procedures like regional anesthesia nerve blocks [3].	Machine Learning for ultrasound image analysis [3].	Enhances accuracy and safety during image-guided techniques.
Postoperative Phase			
Pain Management Optimization	Forecasts patients likely to experience severe pain and analyzes unstructured text to understand nuances of patient recovery [15,16].	Predictive Models [15,20], Natural Language Processing (NLP) [5,16], and ML-driven indices like the Analgesia Quality Index (AQI) [21].	Enables preemptive multimodal analgesia strategies [15]. NLP extracts insights from nurses' notes regarding breakthrough pain or functional limitations [16].
Complication Prediction	Identifies patients at high risk for specific postoperative complications, such as respiratory depression, infection, or readmission [1,9].	Predictive algorithms and Machine Learning models [1,9].	Allows for implementation of enhanced monitoring protocols and targeted interventions for at-risk individuals before deterioration occurs [9].
Remote Patient Monitoring	Continuously monitors patient vitals and recovery progress after discharge from the hospital using data from smart devices [16].	AI platforms integrated with wearable sensors [16].	Facilitates early detection of complications during the vulnerable transition from hospital to home, aiming to reduce readmissions [16].

Automated anesthesia and closed-loop systems

The field of automated anesthesia and closed-loop systems (Table 1) has been the cornerstone of AI's integration into intraoperative monitoring. Comprehensive reviews in 2025 detail the advances in closed-loop systems that use AI to automatically titrate hypnotic and analgesic drugs [13]. These systems utilize physiological modeling and reinforcement learning to adapt to the patient's state, aiming to maintain a steady DoA and stable hemodynamics. Models like Support Vector Machines, Decision Trees, and Gradient Boosting are being evaluated for their accuracy in predicting real-time anesthetic requirements to power these automated systems [10].

Surgical and anesthetic synergy

Furthermore, AI is fostering a new synergy between surgical and anesthetic teams. AI-powered computer vision can track surgical progress, anticipate high-stimulation events (Table 1), and alert the anesthesiologist to prepare for hemodynamic responses [14]. This integration creates a more cohesive and anticipatory intraoperative environment, allowing anesthesiologists to better predict potential hemodynamic changes, specifically during novel or unfamiliar surgical procedures.

AI in postoperative care: Optimizing recovery

The impact of AI is increasingly extending into the postoperative period, focusing on pain management, complication prediction, and facilitating a smoother recovery. These elements are essential aspects of postoperative care to ensure patient safety. AI is being used to predict and manage postoperative pain more effectively (Table 1). Models can forecast which patients are likely to experience severe pain, enabling preemptive multimodal analgesia [15]. Some systems leverage Natural Language Processing (NLP) to analyze patient-reported outcomes and nurses' notes from EHRs to get a richer understanding of a patient's recovery trajectory [16]. Unlike structured vitals or lab results, these narratives often capture nuanced symptoms such as breakthrough pain, anxiety, or functional limitations that are missed by standard monitoring [16]. By integrating all of the data and insights, AI provides a more holistic and patient-centered understanding of recovery trajectories.

Furthermore, AI algorithms can be used to predict the risk of postoperative complications such as respiratory depression, infection, or readmission [9] (Table 1). By identifying at-risk patients early, clinicians can implement enhanced monitoring and targeted interventions. The development of wearable sensors that feed data into AI platforms allows for continuous remote monitoring after discharge, enabling early detection of deterioration [16] (Table 1). This continuous oversight is particularly

important during the vulnerable transition from hospital to home, reducing preventable readmissions and improving long-term outcomes.

Discussion and Future Directions

The current literature demonstrates a notable maturation of AI in anesthesiology, transitioning from theoretical models to validated clinical support tools. The "three pillars" of AI research, prediction, monitoring, and intervention, are now well established across all phases of perioperative care [17]. However, significant hurdles remain. The Anesthesia Research Council highlights barriers, including the need for high-quality, large-scale datasets, the "black box" nature of some complex models, and the challenges of clinical implementation and regulatory approval [18]. To ensure the responsible integration of AI, essential safeguards include robust data governance, transparency, clinician education, and bias mitigation [23].

Future research must focus on model interpretability, ensuring that clinicians can understand and trust AI-driven recommendations. The development of federated learning approaches may help address data privacy concerns, allowing models to be trained across institutions without sharing raw patient data [13]. This collaborative framework is particularly promising for fields with sensitive data, like anesthesia, as it enables the development of more robust, generalizable AI models. Ultimately, the goal is not to replace the anesthesiologist but to augment their capabilities, reducing cognitive load and allowing them to focus on complex decision-making and patient care [5].

Conclusion

Current research highlights the growing integration of AI in anesthesiology, spanning preoperative risk assessment, intraoperative management, and postoperative monitoring. These technologies enhance safety, precision, and efficiency, supporting a shift toward data-driven, personalized care. Despite ongoing challenges in governance and implementation, AI is increasingly seen as a powerful tool to augment rather than replace clinical expertise, empowering anesthesiologists to improve outcomes across the perioperative spectrum.

Conflicts of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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