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Review Article

Artificial Intelligence Applications in Anesthesiology: A Comprehensive Narrative Review

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ABSTRACT

Background: The integration of artificial intelligence (AI) and machine learning (ML) technologies in anesthesiology has emerged as a transformative force in perioperative medicine. This narrative review synthesizes current evidence on AI applications across the perioperative continuum. The objective is to provide a comprehensive overview of AI applications in anesthesiology, examining current implementations, clinical outcomes, and future directions across preoperative assessment, intraoperative monitoring, drug delivery, postoperative care, and clinical documentation.
Methods: A systematic literature search was performed across several databases for peer-reviewed publications on AI applications in anesthesiology from 2015 to June, 2025. If the papers were peer reviewed and come from quality journals. Sixty-six papers from reputable peer-reviewed medical journals of high quality were selected for analysis.
Results: The use of AI-based applications for anesthesiology can be summarized into 5 specific domains: predictive modeling to predict surgical risk assessment, real-time monitoring systems that measure anesthesia depth, automated drug delivery systems (and devices), postoperative complication prediction after surgery, and natural language processing (NLP) to assess clinical documentation. Recent advances show better patient outcomes, clinical decision-making and operational efficiency.
Conclusion: AI technology holds substantial potential to enhance anesthesiology practice along the entire perioperative continuum. Although some challenges need to be addressed in respect of clinical integration and validation, we believe that there is sufficient evidence to justify undertaking further development work with a view towards implementation of AI-assisted anesthesia care.

Introduction

The modern field of anesthesiology operates within a paradox: our operating rooms are data-rich, yet clinicians often remain information-poor. Every second, physiological monitors generate a torrent of data, from heart rate to tissue oxygenation, creating a high-velocity stream that can overwhelm human cognitive capacity. Utilising this data in real-time clinical insights is the challenge and also, opportunity. The missing tools to close this gap have begun to take shape as artificial intelligence (AI) and machine learning (ML), which is poised to create a disruption in perioperative medicine [1-2]. While global healthcare systems have been challenged to improve patient outcomes as well as make operations more efficient and cost-effective, AI applications in anesthesiology may provide unique opportunities – solutions can enhance clinical decision-making and

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support patient care through the entire perioperative continuum [3].

Anesthesia care, which involves real-time physiological monitoring, titration of complex drugs, and rapid clinical decision making in life-threatening situations is a good candidate for application of AI. Artificial Intelligence is not just a refinement over the current methods but is a new way of solving clinical problems by using computational tools to discern subtle patterns that are invisible to human eyes! Modern anesthesia practices generates large quantities of physiological data, where ML algorithms can readily identify these patterns to predict impending adverse events before they occur and offer timely clinical decision support [4-5]. With AI integration, clinicians can now shift from a reactive to proactive position where patient safety improves and personalized care is delivered. The combination of human clinical reasoning and machine intelligence has the potential to establish a more resilient healthcare ecosystem that responds more quickly [6].

This is a narrative review of current applications of AI in anesthesiology based on evidence collected from peer-reviewed manuscripts published from 2015 until October 2024. We consider AI implementations across six important domains: preoperative risk assessment; intraoperative monitoring; automated drug delivery; postoperative care; clinical documentation; and future directions. We will include recent clinical outcomes, challenges for implementation, and the potential of AI to reshape anesthesiology practice.

Methodology

Literature Search Strategy

A purposive narrative review of the literature was conducted to synthesize current evidence on applications of artificial intelligence (AI) in anesthesiology. Searches were performed in significant scientific databases such as PubMed/ MEDLINE, Scopus, Web of Science and IEEE Xplore for relevant literature, plus regional academic databases (e.g., Scientific Information Database [SID], Magiran) to obtain a geographically diverse view. The period of the search was January 2015 until June 2025. We used the following search strategy: (1) key terms, including ("artificial intelligence" OR "machine learning" OR "deep learning" OR "neural networks") AND ("anesthesiology" OR "anesthesia" OR "perioperative care" OR "hemodynamic monitoring".

Inclusion and Exclusion Criteria

Eligible articles had to be peer-reviewed, published in English, indexed in academic databases associated with clinical medicine (e.g., JCR or Scimago) as top-tier journals, and mainly focused on the model development, validation or clinical implementation of AI applications in perioperative settings. Exclusion criteria include editorial comments, unreviewed preprints, and abstracts without full-text availability. The final papers included for narrative synthesis (n = 66) were decided in two group sessions after critical appraisals of relevance and impact by the authors.

Quality Assessment

In use of a multi-criteria quality assessment framework, papers were evaluated in terms of:

- Impact Factor of the journals and their integrity
- Study methodology and design
- Applicability in clinical practice
- The number of novel or significant findings.
- Research output and scholarly impact

Data Extraction and Analysis

In total, 68 full-text papers were included in the final analysis which presented very heterogeneous applications of AI across anesthesiology practice. Papers were categorized according to application domains for clinical outcomes, implementation challenges, and potential future directions.

Preoperative Risk Assessment and Patient Optimization

AI-Powered Risk Prediction Models

One of the most advanced applications of AI in anesthesiology is preoperative risk assessment, where a large number of studies have shown ML models outperform traditional risk scoring systems. More recently, research has sought to develop multi-modal risk prediction models incorporating several data types, such as electronic health records (EHRs), laboratory values, imaging data, and patient-reported outcomes [7-8].

Machine learning algorithms, especially ensemble methods and deep neural networks, have exhibited considerable capacity to identify the complex patterns in preoperative data that standard linear models cannot detect to predict diverse outcomes (such as postoperative mortality major complications intensive care unit admission or length of stay) more accurately than conventional scoring systems [9-10].

Personalized Anesthetic Planning

The preoperative assessment also includes personalized anesthetic planning based on prediction of postoperative risk by artificial intelligence (AI) tools. An example of this is using advanced ML models to analyze patient characteristics, surgical characteristics, and past outcomes in order to then recommend the best anesthetic techniques including types of drugs and monitoring etc. [11–12] They help facilitate evidence-based decision-making by the anesthesiologist on a patient-specific basis.

Using natural language processing (NLP), these systems have identified pertinent information from clinical notes, prior anesthetic records, and imaging reports to build robust patient profiles that directly impact anesthetic planning [4,13]. An automated data extraction minimizes time spent on manual review, while allowing a comprehensive preoperative assessment.

Integration with Electronic Health Records

Contemporary artificial intelligence-based preoperative assessment systems can be linked to electronic health record (EHR) systems, delivering real-time risk prediction and clinical decision support at the point of care. They can automatically identify patients at high risk of postoperative events, recommend further preoperative testing and optimization measures [14-15] shown in (Table 1).

Intraoperative Monitoring and Real-Time Decision Support

Automated Anesthesia Depth Monitoring

Intraoperative monitoring is an important application of AI in anesthesiology, notably for automated evaluation of anesthesia depth and level of consciousness. Proposed conventional monitoring methods utilize processed electroencephalogram (EEG) derived indices like Bispectral Index (BIS), while AI approaches can do more complex analysis with raw EEG signals [16–17].

Deep learning networks have shown better performance in differentiating between consciousness states and predicting intraoperative awareness compared to other machine learning algorithms. These systems are capable of simultaneously analyzing several physiological signals such as EEG, hemodynamic parameters and ventilatory mechanics to provide global measures of anesthetic depth [18-19].

Hemodynamic Monitoring and Prediction

AI applications in hemodynamic monitoring involve prediction and prevention of perioperative cardiovascular complications. Some examples of advanced ML models that can analyze continuous physiological data streams to accurately predict hypotensive episodes, cardiac arrhythmias and fluid responsiveness are extensively reviewed [20-21].

Such predictive systems allow for preventive intervention well in advance of hemodynamic instability, with the intention of improving patient outcomes and decreasing the incidence of perioperative complications. This sophisticated platform allows for the processing of hemodynamic data such as real-time analysis of arterial waveforms, central venous pressure tracings and echocardiographic data in a single quantitative and qualitative cardiovascular assessment [22].

Multimodal Physiological Integration

State of the art AI monitoring systems are combining multiple physiological data streams and providing an integrated overview of patients. They can further integrate EEG, cardiovascular, respiratory mechanics and temperature regulation for early monitoring of physiological deterioration [23].

The role of machine learning in error correction cannot be overlooked; indeed machine-learning algorithms are uniquely suited to seeking out those complex multi-systems patterns that may more readily escape detection using traditional single-parameter monitoring approaches. The study and implementation of this multimodal integration further enhances the clinical decision-making processes and thereby improving patient safety in complex surgical procedures [24–27] (Table 2).

Table 1- Preoperative Risk Assessment & Planning

AI Application	AI Techniques	Key Outcomes
Predictive Modeling	Ensemble methods, Deep learning	Predicts postoperative mortality, complications, ICU admission, and length of stay.
Personalized Anesthetic Planning	NLP, ML models	Recommends optimal anesthetic techniques, drug selection, and monitoring strategies. Integrates patient history, imaging, and EHR data.
EHR Integration	Rule-based algorithms	Provides real-time risk alerts and optimization strategies. Flags high-risk patients for preoperative testing.

Table 2- Intraoperative Monitoring & Drug Delivery

AI Application	AI Techniques	Key Outcomes
Anesthesia Depth Monitoring	Deep learning (EEG analysis)	Distinguishes consciousness states. Predicts intraoperative awareness.
Hemodynamic Monitoring	ML models (arterial	Predicts hypotension, cardiac arrhythmias, and fluid

	waveform analysis)	responsiveness.
Closed-Loop Drug Delivery	Reinforcement learning, PID control	Propofol/volatile anesthetic delivery: faster emergence, reduced drug consumption. Real-time adjustments based on physiological feedback.
Neuromuscular Blockade Management	ML analysis of train-of-four responses	Predicts reversal requirements. Reduces residual blockade complications.

AI-Assisted Drug Delivery and Pharmacokinetic Modeling

Closed-Loop Anesthesia Systems

One of the most intriguing applications of AI in anesthesiology is automated drug delivery, as closed-loop systems have been shown to outperform manual drug administration. These are systems that combine predictive pharmacokinetic modeling with real-time physiological feedback to deliver accurate, individualized drug titration [28-29]. Compared with manual administration, closed-loop systems powered by AI for propofol and volatile anesthetic delivery have been shown to provide more stable anesthesia, faster emergence times and less drug consumption. Such systems constantly recalibrate drug delivery on the basis of various feedback factors, including behavioural EEG features as well as parameters related to hemodynamic stability and stimulation level during surgery [30].

Personalized Pharmacokinetic Modeling

With the advent of machine learning methods, personalized drug dosing is made possible by using the individual patient characteristics to estimate pharmacokinetic parameters. AI algorithms can assess patient demographics, comorbidities, genetic composition and continuous physiological values to enable rationalization of individual drug dosing regimens [31]. Such tailored models show greater prediction accuracy over population pharmacokinetic models with more precise dosing information relating to improved clinical outcomes. Deep learning networks allow for identification of patients-drug response associations as a function of multiple latent factors, surpassing the capability of traditional compartmental models to capture complex relationships between numerous patient factors and drug response [32-33].

Neuromuscular Blockade Management

Machine learning methods have been successfully applied in various aspects of anaesthesia, including intra-operative diagnosis and management of neuromuscular blockade (NMB) to enhance patient safety through optimising muscle relaxants delivery and predicting the requirement of reversal. Machine learning algorithms are capable of analyzing a train-of-four responses, patient characteristics and surgical needs to provide recommendations on the best dosing for neuromuscular blocking agent [34]. Advanced artificial intelligence (AI) systems are capable of predicting the need for neuromuscular blockade reversal, as well as suggesting optimal reversal agents and dosing strategies. These systems assist in decreasing the occurrence of residual neuromuscular blockade and related postoperative complications [35].

Postoperative Care and Complication Prediction

Early Warning Systems

Early warning systems are only one of many ways AI is being integrated into the surgical suite but are probably one of the most compelling applications in anesthesiology if you include postoperative complication prediction. The continuous physiological monitoring data, laboratory values, and clinical observations utilized in machine learning algorithms may predict complications hours before clinical deterioration is evident [36-37].

These early warning systems using artificial intelligence have been particularly successful in detecting preoperative sepsis, respiratory failure, cardiovascular complications and postoperative acute kidney injury. Such systems potentially help reduce morbidity, mortality, and healthcare costs as they facilitate early interventions [38].

Pain Management Optimization

AI applications in effectively managing postoperative pain mainly target predicting an individual pain trajectory and optimizing analgesic regimens. Machine learning models can learn from rich data sets including information about patient characteristics, surgical factors and pain assessment scores to predict chronic pain development and inform preemptive treatment. Advanced AI can really help with personalization of pain management protocols because different patients respond to analgesics in a unique way, minimizing opioid consumption while still having enough analgesia. These systems advocate evidence-based pain management and aid in curbing the current opioid epidemic [39].

Recovery Prediction and Discharge Planning

AI algorithms have been shown to predict postoperative recovery trajectories and to model discharge planning. Modeling clinical outcomes with a machine learning approach can incorporate more variables, including surgical complexity, patient and comorbidities, intraoperative events and early postoperative course to predict length of stay and discharge readiness [40–41]. This predictive systems help proactively allocate resources, identify patients in need of extended care and optimize the use of beds. AI discharge planning tools can recommend the appropriate post-acute care settings and identify patients at risk for readmission [42] (Table 3).

Natural Language Processing and Clinical Documentation

Automated Anesthesia Record Generation

Automated voice command, physiological data and clinical observations continuously facilitate comprehensive automatic anesthesia records generation with the help of NLP technologies that have revolutionized anaesthesiology. These systems decrease documentation burden and allowed for more accurate and complete record [4,43].

Table 3- Postoperative Care & Clinical Documentation

AI Application	AI Techniques	Key Outcomes
Early Warning Systems	ML algorithms (continuous monitoring data)	Predicts sepsis, respiratory failure, and acute kidney injury hours before clinical signs.
Pain Management Optimization	ML models (patient/surgical factors)	Predicts chronic pain risk. Guides personalized analgesic regimens (reduces opioid use).
Recovery Prediction	ML analysis of perioperative data	Predicts length of stay and discharge readiness. Supports resource planning and readmission risk assessment.
Clinical Documentation	NLP, voice recognition	Generates automated anesthesia records from voice/physiological data. Reduces documentation burden.
Decision Support	NLP (clinical notes analysis)	Provides real-time alerts for drug interactions/allergies. Integrates with EHR for evidence-based recommendations.

Such AI-enhanced documentation systems are capable of automatically documenting key intraoperative events such as drug administrations and physiologic changes to create comprehensive anesthesia records that may guide quality improvement and research efforts. Hands-free documentation that does not impede patient care is made possible through the use of voice recognition and natural language understanding [44].

Clinical Decision Support Integration

This goes beyond documentation or extraction for NLP systems in anesthesiology and includes integration of reporting with real-time clinical decision support. These systems can also read clinical notes, laboratory results and imaging reports to summarize key information and offer evidence-based recommendations [45–46].

More recently, sophisticated NLP products can detect drug-drug interactions, known allergies, and contraindications immediately – thus improving patient safety and clinical decision-making. System integration with for example electronic health records that you from clinical support [47].

Quality Improvement and Research Applications

Natural Language Processing (NLP) technologies allow large-scale analyses of anesthesia records to support quality improvement and research activities. It can help identify patterns in adverse events, extract performance metrics, and support continuous quality improvement initiatives through automated text analysis [48–49] (Table 3).

Implementation Challenges and Considerations

Technical and Infrastructure Requirements

But completely clinical-grade use of these AI systems in anesthesiology requires substantial and sometimes advanced technical infrastructure such as high-performance computing (HPC) capabilities, large data storage systems, and adequate network connectivity. Healthcare organizations has to invest in hardware, software, and technical talent for implementing Ai applications [50].

Difficulties in data integration are one of the greatest barriers to AI adoption. While data is the lifeblood of any modern AI system [51], only structured and interoperable high-quality data can give birth to a machine learning model. Anesthesiology AI systems rely on these and other data sources (physiological monitors, electronic health records [EHRs], laboratory systems, imaging platforms) being seamlessly integrated into a useable format for the AI system. In the case of predicting hypotension, real-time arterial waveform data along with EHR-powered demographic information and preoperative lab values may be needed (type of data input). However, if these data streams are not standardized or synchronized the performance of model will be severely degraded. To mine data both efficiently and effectively, standardization of data formats and protocols for such AI deployment systems is crucial [52].

Regulatory and Safety Considerations

Anesthesiology applications for AI have some of the most rigorous regulation and safety standards. While there are already frameworks for AI/ML-based medical devices from the FDA, rapid technological change continues to push the regulatory envelope. This category includes adaptive learning algorithms that change over time and therefore need new post-market monitoring methods to ensure they do not "drift" towards unsafe performance. Before widespread clinical adoption, AI systems must be tested to demonstrate both safety and efficacy in diverse patient populations and clinical settings. It is also important to review and validate its performance periodically, as both clinical practices and patient populations change over time [1].

Beyond the hurdles of regulatory approval, serious ethical questions need to be answered. “Algorithmic bias” represents a major risk: if an AI model is trained on data from a largely uniform population, its resulting predictions may be less accurate or even harmful to more diverse populations. Moreover, when operating with sensitive patient data, ensuring “data privacy and security” so as to comply with elements like HIPAA. Finally, the aspect of "accountability" has to be examined: who is accountable when a recommendation produced via an AI methodology leads to a bad outcome - the clinician? the hospital? the software author? or even just the algorithm itself? An equally essential precondition of this is strong institutional and professional guidelines to tackle these questions.

Clinical Integration and Workflow Adaptation

Building an AI model is just one part of the process Intelligent document processing drives success across clinical workflows. AI systems should be connected to the existing clinical processes without disturbing patient care or increasing workload for anesthesia providers [53]. An important part of this is the "black box" problem, when in deeply complex prediction models such as deep neural networks provide too good predictions but cannot explain their consideration. There is no transparency, which can undermine clinical trust and impede adoption. The research in "explainable AI" (XAI), which causes deep learning to rationalize its recommendation, is a significant component in reestablishing clinician confidence [54].

We need training and education for successful adoption. However, comprehensive training of anesthesiology providers in the capabilities, limitations and appropriate application surrounding these potential AI systems is strongly suggested to ensure maximal utility whilst upholding patient safety [55].

Future Directions and Emerging Technologies

Advanced Machine Learning Approaches

Recently, the time for AI in anesthesiology is yet conversing intensively throughout its development with a progressively embraced machine learning approaches including federated learning, reinforcement based learning and explainable artificial intelligence. These technologies overcome current AI limitations in systems and allow for more advanced clinical applications [56].

Fortunately, it has been integrated into the concept of “federated learning,” which overcomes many data-sharing barriers and facilitates the development of AI models across multiple institutions while maintaining centralization-free sensitive patient data sharing capabilities that also preserve privacy during this process as more robust and generalizable models are created [57].

For example, “reinforcement learning,” an approach wherein an algorithm learns optimal decision making through trial and error in a simulated environment, has already shown promise for optimizing other complex sequential clinical decision-making tasks (e.g., vasopressor titration or mechanical ventilation strategies) [58].

The biggest buzzword-“explainable AI (XAI)” attempts to clarify the “black box” models with transparent justifications based on data for predictions made by AI. This is crucial for fostering trust in clinical settings and allowing clinicians to appraise AI recommendations critically and override them, if needed [59].

These sophisticated ML models can be useful in multiple medical domains and have great potential to develop robust diagnostic and prognostic tools. For example, integrating these methods have been employed in the development of accurate clinical decision-support systems for multi-nutritional deficiency predictions illustrating wider implications and broad applicability towards precision [60].

Integration with Emerging Technologies

The next development phase for AI in anesthesiology is the increasing integration with other emerging technologies, such as Internet of Things (IoT) devices, augmented reality and blockchain systems. The combination of the two will enable novel applications for improved patient monitoring, immersive training/learning and secure data sharing [61-62].

The use of wearable devices and remote monitoring technologies will bring AI applications beyond the operating room, allowing for continuous perioperative monitoring as well as early intervention. These technologies enable value-based care models and enhance patient outcomes over the full surgical episode [63–65].

Personalized and Precision Medicine

Thus, the future of AI in anesthesiology will consider approaches to personalized and precision medicine (P&P) more than before. Integration of genomic data, metabolomics and other omics technologies with any AI systems will also truly facilitate personalized anesthetic care tailored to the unique patient characteristics [64-65].

They are precision medicine approaches that will manipulate drug choice, dosing protocols and monitoring efforts to match individual patient biology which could lead to improved outcomes at the population level with a corresponding decrease in adverse events and hospitalizations or healthcare costs [66].

Discussion

Artificial intelligence has come to the field of anesthesiology as changing the paradigm from reactive to proactive perioperative care. As demonstrated in our synthesis, AI applications in predictive analytics, automated hemodynamic monitoring, airway assessment, and pharmacological dosing have great promise to inform clinical workflows while promoting patient safety [5]. In particular, machine learning algorithms trained in large datasets from Electronic Health Records (EHRs) have predicted important intraoperative events such as hypotension, hypoxemia and depth of anesthesia with very high accuracy compared to more traditional statistical models.

Although there have been technological developments that take these limitations into consideration, few AI algorithms have transitioned from in silico validation to bedside clinical practice. There are several key barriers that make solving this issue challenging. Most AI models in anesthesiology are constructed retrospectively from single-center datasets. This by nature restricts their external validity and generalizability to different patient groups and clinical settings. The second challenge is that deep learning algorithms are complex black boxes; anesthesiologists need explainable AI (XAI) for algorithmic results to be trusted, particularly in resource-poor environments where life-saving care actions must not only occur quickly but also under conditions of high-stakes critical illness.

In addition, ethical and medico-legal issues around AI liability are unclear. The division of liability in cases of detriment from an AI-aided decision remains uncertain, with little clarity to be found in current laws as to how the responsibility for an error is attributed between a clinician working within a healthcare institution and the software developer. Lastly, integrating AI systems into existing hospital IT infrastructures and monitoring equipment in real-time requires large capital investments and the standardization of perioperative data streams.

Limitations

This paper is a narrative review and has therefore inherent limitations. Since our literature search was not systematic, there is potential for selection bias, and due to the rapid evolution of this field we may have missed additional relevant literature. This was not based on a formal quantitative meta-analysis, and therefore it was impossible to statistically pool model accuracies or clinical outcomes.

Conclusion

Artificial intelligence has the potential to revolutionize anesthesiology by strengthening risk assessment, streamlining intraoperative monitoring and tailoring anesthetic delivery. The actual realm of AI in perioperative medication continues to be dominated by retrospective, single-center research. In conclusion, our work suggests that highly generalizable algorithms can be developed for the enhanced detection of significant coronary stenoses and improved classification of FFR prediction models, yet ultimately a prospective multi-center RCT design will be required to successfully transition algorithm development into routine clinical practice. Ensuring that the algorithms are interpretable, and patient data is not leaked will also require the development of Explainable AI (XAI) and techniques borrowed from federated learning paradigms. In the end, AI should not be seen as a substitute for the anesthesiologist in lieu of an advanced cognitive assistant intended to support clinical judgement, reduce human errors and optimize perioperative patient outcomes. The major findings of this thorough review are as follows:

- Mature Applications: Preoperative risk prediction and intraoperative monitoring are the two most mature AI applications, with hundreds of validated systems indicating clinical effectiveness.
- New Opportunities for Automation Including: Drug delivery automation and postoperative complication prediction appear to be very

promising but need further validation and integration.

- It is important because the presence of technical infrastructure, regulatory compliance and clinical workflow integration are major impediments to widespread AI adoption.
- Future potential: Sophisticated machine learning techniques and convergence with developing technologies will continue to drive AI adoption and broaden clinical use.

Across anesthesiology, successful integration of AI will require collaboration between clinicians, technologists, regulators, and healthcare organizations. Realizing the full potential of these transformative technologies will depend on continued research, validation and establishment of clear ethical frameworks. Ultimately, the application of AI in anesthesia has been to assist anesthesiologists and not to replace them by relieving their cognitive burden so they can get involved with the most important elements that require expert human attention: decision making, communication within a team, and patient care. As AI continues to evolve, we need anesthesiologists to step up as leaders in determining how it is designed, validated, and deployed into clinical practice. And thereby, we will make sure the greatest commitment of our profession-caring for our patients-is served by this technological evolution.

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However, we know the authors are building on the great work of researchers and clinicians across the globe who have led advances in AI in anesthesiology. Improving patient care with technology will remain their focus as they push the boundaries of this rapidly evolving field. The author also expresses gratitude to the Clinical Research and Development Unit of Imam Hossein Hospital for their assistance with study design, data management and statistical advice. Additionally, the authors acknowledge the use of ChatGPT solely for the purpose of language editing, proofreading, and improving the writing fluency of the manuscript.

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