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LITERATURE REVIEW

Artificial Intelligence in Anesthesiology and Intensive Care: Recent Developments, Clinical Applications, Clinical Decision Support Systems and Implementation Challenges in the Era of Digital Medicine

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ABSTRACT

Artificial Intelligence (AI) is rapidly evolving and has become a transformative innovation in anesthesiology and intensive care. Technologies such as machine learning, deep learning, clinical decision support systems (CDSS), and Generative Artificial Intelligence (GenAI) offer significant potential to enhance clinical practice. This literature review discusses recent developments, clinical applications, implementation challenges, and future directions of AI in anesthesiology and intensive care units (ICU). Studies indicate that AI can enhance preoperative assessment through more accurate risk stratification, predict intraoperative hypotension, optimize fluid therapy and hemodynamic management, assist with monitoring anesthesia depth, and support ultrasound-guided regional anesthesia. In intensive care units, AI contributes to early sepsis detection, prediction of acute kidney injury, optimization of mechanical ventilation, identification of multiorgan failure risk, and mortality prediction. The emergence of GenAI and Large Language Models (LLMs) has further expanded AI applications in medical education, literature reviews, research, clinical documentation, and guideline development. However, AI implementation continues to face challenges, including limited prospective validation, algorithmic bias, insufficient explainability, the risk of LLM hallucinations, data security concerns, and ethical and medicolegal issues. Artificial Intelligence (AI) is not intended to replace anesthesiologists, but it serves as augmented intelligence that supports evidence-based clinical decision-making. Responsible AI implementation requires strengthening digital infrastructure, developing algorithms based on local data, and increasing literacy. Artificial Intelligence (AI) for health workers, as well as regulations that ensure security, transparency, and accountability. With this approach, AI has the potential to improve the quality, safety, efficiency, and personalization of anesthesiology services and intensive care.

Keywords: Artificial intelligence; anesthesiology; intensive care; machine learning; clinical decision support system; large language models.

INTRODUCTION

Artificial Intelligence (AI) has become one of the most transformative technologies in modern healthcare. Advances in computing, the growing availability of big data, the use of electronic medical records, and progress in machine learning and deep learning algorithms enable AI to analyze multidimensional clinical data more quickly and accurately than conventional computational methods. Studies have shown that AI can improve early disease detection, predict clinical outcomes, support data-driven decision-making, and enhance service efficiency and patient safety.[1-6] Among various medical disciplines, anesthesiology and intensive care are highly potential fields for the application of AI due to their characteristics that rely on continuous physiological monitoring and short-term decision-making.

During the perioperative period as well as treatment in the intensive care unit (ICU), the anesthesiologist must integrate various dynamically changing physiological parameters, such as invasive blood pressure, electrocardiography, capnography, pulse oximetry, anesthesia depth index, mechanical ventilation, blood gas analysis, and laboratory test results. This complexity makes AI one of the promising technologies to be developed as a clinical decision support system (CDSS), which is a system that is able to help clinicians recognize physiological changes early, predict complications, and provide data-driven recommendations in real-time.[1,3,7-11]

AI development in anesthesiology has produced diverse clinical applications across the perioperative continuum. Preoperatively, AI algorithms can stratify patient risk, predict mortality, identify difficult airways, and estimate the need for postoperative intensive care. Intraoperatively, AI has been used to predict hypotension, optimize fluid therapy, support hemodynamic management, regulate mechanical ventilation through closed-loop systems, and assist in assessing anesthesia depth. In the intensive care unit, AI can support early sepsis detection, predict acute kidney injury (AKI), identify the risk of multiorgan failure, estimate mortality, and help optimize therapy for critically ill patients. These advances strengthen the concept of precision perioperative medicine, an approach that tailors care to each patient's physiological characteristics and individual risk profile.[7-11]

Beyond clinical prediction, the emergence of Generative Artificial Intelligence, particularly large language models (LLMs), has introduced new opportunities in anesthesiology education, research, and practice. LLMs, including ChatGPT and similar technologies, are increasingly used to support literature reviews, summarize clinical guidelines, assist scientific writing, develop educational materials, and facilitate medical documentation. Despite their considerable potential, LLMs require cautious use in clinical practice because of the risk of hallucinations, limited transparency in decision-making processes, and insufficient clinical validation as a basis for independent medical decision-making.[12-13]

Although the development of AI is very rapid, its implementation in the practice of anesthesiology still faces various challenges. The success of AI adoption is not only determined by algorithm performance, but also influenced by data quality, readiness of digital infrastructure, interoperability of information systems, security and confidentiality of patient data, algorithm transparency (explainable artificial intelligence), as well as ethical, legal, and accountability aspects of the use of AI in healthcare. In addition, the level of user acceptance and clinical trust in AI systems are also important factors that determine the success of the implementation of the technology.[14-20]

A recent international survey of anesthesiologists and intensive care professionals from multiple countries found generally positive attitudes toward AI use in clinical practice. Most respondents believed that AI could improve decision-making, support early complication detection, enhance patient safety, and reduce administrative workload. However, they also highlighted the need for robust clinical validation, algorithm transparency, clear regulation, and well-defined professional responsibilities before AI can be widely adopted in patient care.[21]

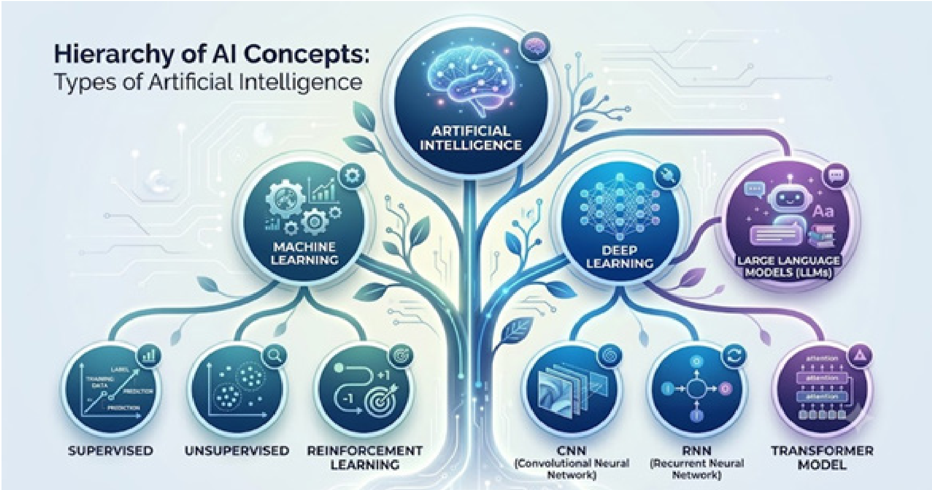

Figure 1. Types of AI

Based on these developments, a comprehensive understanding of the basic concepts of AI, the latest scientific evidence, various clinical applications in the perioperative and intensive care periods, the use of clinical decision support systems and large language models, as well as the challenges of implementation and the direction of its development are very important for anesthesiologists and intensivists. Therefore, this literature review aims to present the latest developments in the use of AI in anesthesiology and intensive care, with an emphasis on the latest scientific evidence, clinical implications, implementation challenges, and opportunities for its application in the health care system in Indonesia.

Key Components of Artificial Intelligence in Anesthesiology Practice

Artificial Intelligence (AI) is a term that encompasses various computing methods with different characteristics and applications. In the field of anesthesiology and intensive care, the most widely used AI technologies include machine learning (ML), deep learning (DL), natural language processing (NLP), computer vision, and large language models (LLMs). Each technology has a complementary role in supporting clinical decision-making, physiological data analysis, interpretation of medical images, and automation of documentation and medical education.[4-610-11] Machine learning is a branch of AI that enables computers to identify relationships among variables from data without explicit programming for each condition. These algorithms build predictive models from patterns in training datasets and apply them to new data to generate predictions or classifications. In anesthesiology, ML has been used to predict intraoperative hypotension, vasopressor requirements, postoperative complications, perioperative mortality, the need for ICU admission and acute kidney injury (AKI). Compared with conventional statistical models, ML can better capture nonlinear relationships and complex interactions among variables, often achieving stronger predictive performance, particularly in large-scale clinical datasets.[1,8-9,11,22-23]

Based on the learning method, ML is divided into three main groups, namely supervised learning, unsupervised learning, and reinforcement learning. Supervised learning is the most widely used approach in anesthesiology research because it utilizes data that already has an output (label) to build prediction models. On the other hand, unsupervised learning is used to identify patterns or subphenotypes of diseases without predetermined outcomes, for example in the classification of sepsis or acute respiratory distress syndrome (ARDS) patients. Meanwhile, reinforcement learning has begun to be developed to dynamically optimize therapy strategies through a feedback-based learning process, although its application in anesthesiology is still relatively limited.[2-4.9]

Deep learning is the development of machine learning that uses layered artificial neural networks to automatically learn complex data representations. The main advantage of DL is its ability to extract important characteristics from raw data without the need for manual feature engineering. This approach is very effective in processing high-dimensional data, such as continuous physiological signals, ultrasound images, electrocardiography, electroencephalography, and other medical imaging data.[1.5-6,8,11]

n anesthesiology, DL has been used to identify hypotension patterns before clinically significant blood pressure changes occur, interpret ultrasound images for regional anesthesia, detect airway anatomical structures, and support anesthesia-depth analysis using electroencephalography signals. Integrating DL with real-time physiological monitoring systems also enables earlier detection of patient deterioration, allowing more timely clinical intervention.[5,11,22-23]

Natural Language Processing (NLP) is a branch of AI that allows computers to understand, extract, and generate human language. In health services, most clinical information is still stored in the form of unstructured clinical notes, such as patient development records, anesthesia reports, consultations, and discharge summaries. NLP allows that information to be transformed into structured data that can be further analyzed by AI algorithms.[4,6,11]

In the field of anesthesiology, NLP is beginning to be used to extract diagnoses, identify perioperative complications, evaluate adherence to clinical guidelines, and support electronic medical record-based research. In addition, this technology has the potential to reduce the burden of administrative documentation through the automation of the preparation of medical reports and the extraction of critical information from electronic medical records.[11.13]

Computer vision is an AI technology that allows computers to recognize objects, patterns, and anatomical structures through the analysis of digital images or videos. In anesthesiology, computer vision has great potential to improve the accuracy of imaging-based actions, especially in the use of perioperative ultrasound and regional anesthesia. AI systems can help automatically recognize peripheral nerves, blood vessels, pleura, epidural space, and other anatomical structures, increasing the success of the procedure while reducing complications.[1,5,8,11] In addition, computer vision is being developed to support airway assessment by analyzing images of the face, oral cavity, and neck structures. This approach may improve difficult-airway prediction compared with conventional clinical assessment, although prospective validation in larger populations is still required before routine implementation.[11,22]

The most recent advances in AI include the emergence of large language models (LLMs), transformer-based models trained on billions of words from diverse sources to understand and generate contextually relevant text. Unlike conventional ML algorithms, which primarily focus on numerical prediction, LLMs are designed to process natural language and can support a wide range of academic and administrative tasks in anesthesiology.[12-13]

Various studies have shown that LLM has the potential to help review literature, summarize clinical guidelines, prepare learning materials, produce educational evaluation questions, improve the grammar of scientific manuscripts, and assist with medical documentation. However, LLMs still have limitations in the form of the possibility of producing inaccurate information (hallucinations), difficulties in conducting complex clinical reasoning, and the lack of adequate validation to be used as an independent medical decision-making system. Therefore, all LLM outputs must remain verified by physicians before being used in clinical practice or scientific publications.[12-13]

Artificial Intelligence in Preoperative Evaluation

Preoperative evaluation is a stage that

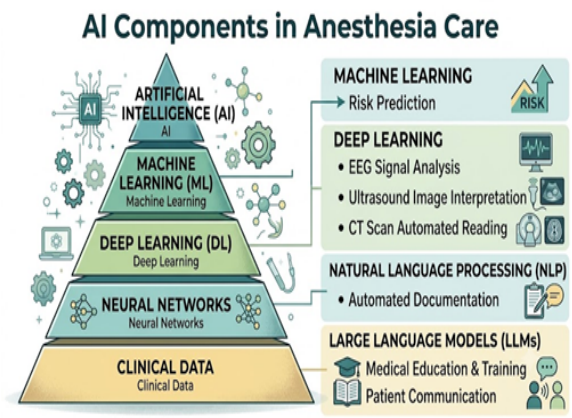

Figure 2. Components of Artificial Intelligence in Anesthesia Services

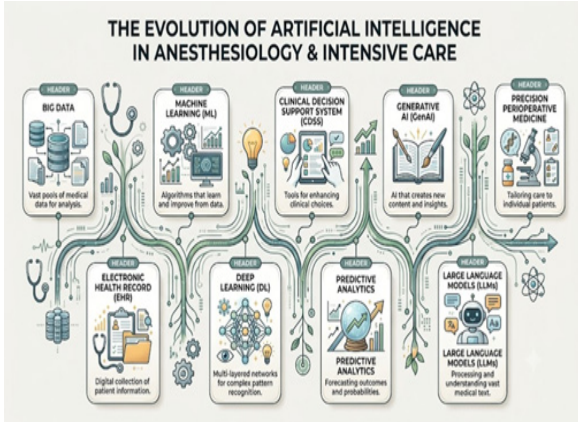

Figure 3. The Development of Artificial Intelligence in Anesthesiology and Intensive Care (ICU)

greatly determines the success of perioperative management. In this phase, the anesthesiologist identifies comorbidities, assesses the patient's functional status, evaluates anesthesia and surgical risks, and plans the most appropriate anesthesia strategy. The accuracy of risk assessment in the preoperative period has a direct effect on the incidence of intraoperative complications, the need for intensive care, the length of hospitalization, and patient mortality. Despite various risk assessment systems such as the American Society of Anesthesiologists Physical Status (ASA-PS), Revised Cardiac Risk Index (RCRI), Snoring, Tiredness, Observed apnea, high blood pressure, Body mass index, Age, Neck circumference and Gender (STOP-BANG), and Clinical Frailty Scale (CFS) is still widely used, such models have limitations because most of them are developed using conventional statistical approaches that are difficult to capture the complex relationships between clinical variables.[1:8-11]

Artificial Intelligence enables a new approach to perioperative risk stratification by using machine learning to analyze thousands of clinical variables simultaneously. Unlike traditional regression models, which typically assume linear relationships, ML algorithms can identify the nonlinear associations and complex interactions commonly seen in patients with multiple comorbidities. By integrating data from electronic medical records, laboratory results, medical history, medication use, physiological parameters, and surgical characteristics, AI models can generate more individualized risk predictions.[1,4,6,9-10]

Perioperative mortality and morbidity prediction is one of the most widely studied AI applications. Various ML algorithms have demonstrated strong performance in estimating the risk of major complications, 30-day mortality, postoperative mechanical ventilation, and the need for ICU care. Compared with conventional risk assessment systems, AI models offer greater discriminatory ability because they can dynamically integrate large volumes of clinical data. Beyond improving predictive accuracy, this approach helps anesthesiologists communicate risk more objectively to patients and families and supports the selection of perioperative strategies tailored to each patient's characteristics.[10-11,22-23]

A 2024 meta-analysis of research journal publication showed that machine learning-based interventions in perioperative care as a whole are associated with improved quality of clinical decision-making and a decrease in some perioperative complications, although large-scale prospective research is still needed to ensure its benefits to long-term clinical outcomes.[23] Similarly, a 2024 systematic review journal publication concluded that AI-assisted perioperative management provides benefits primarily in risk prediction and hemodynamic management optimization, but the quality of the evidence between studies is still heterogeneous,

Tabel 1. Snoring, Tiredness, Observed apnea, high blood Pressure, Body mass index, Age, Neck circumference and Gender (STOP-BANG)

Letters	Abbreviation	Criteria
S	Snoring	Is the patient snoring loudly (louder than speaking or being heard through a closed door)?
T	Tiredness	Do patients often feel tired, sleepy, or fatigued during the day?
O	Observed apnea	Has anyone ever observed a patient stop breathing while sleeping?
P	Pressure	Does the patient have hypertension or is undergoing hypertension treatment?
B	Body Mass Index (BMI)	BMI > 35 kg/m²
A	Age	Age > 50 years old
N	Neck circumference	Neck circumference > 40 cm
G	Gender	Male

Note: Interpretation of the Score
1. 0–2 points → Low risk of OSA
2. 3–4 points → Moderate risk of OSA
3. 5–8 points → High risk of OSA
4. Patients are also considered to be at high risk when:
   • STOP ≥2 and BMI >35 kg/m², or
   •STOP ≥2 and neck circumference >40 cm, or
   •STOP ≥2 and male

so routine implementation needs to be done carefully.[22] Identifying difficult airways remains an important challenge in anesthesiology. Conventional assessment methods, including Mallampati scores, thyromental distance, sternomental distance, and upper lip bite tests, show variable sensitivity and specificity. In recent years, AI has been developed to improve difficult airway prediction by analyzing facial images, neck structures, ultrasound findings, and combined anthropometric parameters using deep learning algorithms.[1,8,11]

The Artificial Intelligence-based approach allows the identification of anatomical characteristics that are difficult to recognize through regular clinical examinations. Although initial results show promising performance, most studies are still conducted in a single population with limited sample sizes so external validation is needed before this technology can be integrated into routine practice.[1.11]

Planning ICU bed requirements is an important part of perioperative management, particularly in hospitals with limited capacity. Artificial Intelligence can predict postoperative ICU needs by integrating patient characteristics, comorbidities, surgical type and duration, laboratory findings, and preoperative physiological data. These prediction models can improve hospital resource allocation and reduce delays in transferring critically ill patients to the ICU.[3,7,10-11]

everal studies have shown that ML models have better predictive performance than conventional score-based approaches. However, the success of its implementation relies heavily on the quality of electronic medical records, the interoperability of hospital information systems, and the validation of algorithms in local populations.[7.10] Precision perioperative medicine is a rapidly evolving concept in modern anesthesiology that tailors' anesthesia strategies to each patient's individual characteristics. Artificial Intelligence is central to this approach because it can integrate clinical data, genomics, biomarkers, laboratory results, and physiological parameters into more personalized predictive models.[4,10-11]

This approach allows anesthesiologists to develop more specific perioperative plans, including the selection of anesthesia techniques, fluid therapy strategies, invasive monitoring needs, the use of vasopressors, and the anticipation of postoperative complications. Thus, Artificial Intelligence has the potential to shift the paradigm of service from a population-based approach to a service that is truly centered on the characteristics of each patient.

Despite their considerable potential, AI applications in preoperative evaluation still face several barriers. Most models are developed from retrospective data collected in tertiary hospitals with well-established electronic medical record systems, which may limit their generalizability to other healthcare settings. Differences in patient characteristics, data quality and anesthesia practices across countries can also affect algorithm accuracy when models are applied to different populations.[10-11,22]

In Indonesia, AI implementation in preoperative care should begin with standardized anesthesia documentation, improved electronic medical record quality, and the development of a national perioperative registry. These steps would provide a representative database for developing AI algorithms tailored to Indonesian patient characteristics and support the gradual adoption of precision perioperative medicine.

Artificial Intelligence in Intraoperative Management

The intraoperative phase is the most dynamic period of anesthesia care, marked by rapid physiological changes in response to anesthesia induction, surgical stimulation, bleeding, shifts in intravascular volume, and anesthetic drug administration. Anesthesiologists must interpret multiple physiological parameters simultaneously and make decisions within seconds. This complexity makes intraoperative management especially suitable for Artificial Intelligence (AI) applications, particularly as a clinical decision support system (CDSS) that continuously analyzes data, detects early physiological changes, and provides real-time clinical recommendations.[1,8-11]

In contrast to conventional monitoring systems that are reactive, AI enables a predictive monitoring approach, which is the ability to predict a clinical event before a physiological change reaches a threshold that can be visually recognized by clinicians. This approach is expected to be able to speed up interventions, reduce therapy delays, and improve the patient's physiological stability during surgery.[1.10-11.23]

Intraoperative hypotension (IOH) is one of the most common complications during general anesthesia and has been associated with an increased risk of acute kidney injury, myocardial injury, stroke, postoperative delirium, and increased mortality. Therefore, the prevention of hypotension is one of the main focuses of AI research in the field of anesthesiology.[11:22-23]

Advances in machine learning have enabled algorithms to predict hypotension several minutes before blood pressure decreases. One of the most widely studied systems is the Hypotension Prediction Index (HPI), which uses arterial waveform analysis to detect hemodynamic changes that occur before hypotension develops. Systematic reviews and meta-analyses show that HPI can reduce the duration of intraoperative hypotension and improve early detection compared with conventional monitoring, although its effect on long-term clinical outcomes requires further investigation.[22-23]

Beyond the Hypotension Prediction Index (HPI), several deep learning and gradient boosting models have also demonstrated strong predictive performance, with high area under the receiver operating characteristic curve (AUROC) values across different surgical populations. However, model performance may be affected by monitor signal quality, patient characteristics, and variations in anesthesia practice across institutions; therefore, external validation remains necessary before widespread implementation.[8-10]

Artificial Intelligence is increasingly being used in intraoperative hemodynamic management by integrating arterial pressure, heart rate, stroke volume variation, cardiac output, and other physiological parameters. Through predictive algorithms, AI systems can help identify the underlying cause of hemodynamic instability, such as hypovolemia, vasodilation, or impaired myocardial contractility, and guide clinicians in selecting appropriate interventions, including fluid administration, vasopressors, or inotropes.[10-11,22-23]

This approach supports goal-directed hemodynamic therapy (GDHT), a strategy aimed at maintaining organ perfusion by optimizing individualized hemodynamic parameters. Compared with threshold-based monitoring algorithms, AI systems can detect trends in physiological changes, allowing earlier and more precise interventions.[22-23]

Determining the need for intraoperative

fluids is a challenge because excessive fluid administration can lead to tissue edema and impaired wound healing, while excessive fluid restriction increases the risk of organ hypoperfusion. AI offers a more individualized approach by integrating continuous hemodynamic data, patient characteristics, blood loss, and response to previous therapies to predict fluid responsiveness.

Artificial Intelligence models can help determine the optimal timing and volume of fluid administration while dynamically assessing therapeutic responses. As a result, fluid management decisions are not based on a single physiological parameter but on multidimensional analysis of the patient's overall condition.[1,9-11] Closed-loop anesthesia is one of the most promising developments in anesthesiology. This automated system continuously adjusts anesthetic drug delivery based on the patient's physiological data. It uses inputs from anesthesia-depth monitors, hemodynamic parameters, and neuromuscular monitoring to allow AI algorithms to calculate real-time drug requirements and control infusion pumps through a feedback control mechanism.[8-10]

Several studies have shown that closed-loop systems can maintain Bispectral Index (BIS) targets more consistently than manual titration, reduce fluctuations in anesthesia depth, and decrease anesthetic drug consumption in some surgical procedures. However, clinical use remains largely limited to research centers and requires further evaluation of safety, system reliability, and clinician acceptance.[11,22]

Electroencephalography (EEG) signal interpretation is one of the fastest-growing applications of deep learning in anesthesiology. Unlike conventional indices that rely on fixed algorithms, AI can learn complex patterns of brain electrical activity and may provide a more accurate assessment of anesthesia depth. Artificial Intelligence may also help identify conditions associated with anesthetic awareness, burst suppression, and delayed recovery of consciousness. The integration of AI with EEG monitors is expected to support more individualized anesthesia, reduce the risk of overdose and underdose of anesthesia drugs, and improve patient safety, especially in the geriatric population and patients with neurological disorders.[8-9,11]

The development of computer vision allows AI to help interpret ultrasound images automatically. In regional anesthesia, AI can recognize peripheral nerves, blood vessels, fascia, pleura, and other musculoskeletal structures to improve the success of regional blocks and reduce complications. In addition, the integration of AI with point-of-care ultrasound (POCUS) has begun to be developed to help evaluate heart function, intravascular volume status, diaphragmatic function, and quickly identify pulmonary complications in the operating room and ICU. Although early results show promising potential, most of these technologies are still in the clinical validation stage.[1,8,11]

Although AI is showing a growing ability to support intraoperative decision-making, its implementation still faces various obstacles. Poor monitor signal quality, physiological artifacts, variations in anesthesia techniques, heterogeneity of patient populations, and differences in monitoring devices can affect the performance of the algorithm. In addition, most AI models are developed using retrospective data from tertiary hospitals so they require multicenter prospective validation before they can be widely applied.[10-11,22-23] In Indonesia, AI should be introduced gradually during the intraoperative phase. Initial priorities include improving digital documentation quality, standardizing anesthesia monitoring data, and integrating electronic medical records with monitoring devices. These steps would create the database needed to develop AI algorithms tailored to Indonesian patient characteristics and support the sustainable implementation of precision perioperative medicine.

Artificial Intelligence in Intensive Care Unit

Intensive care involves highly complex clinical decision-making. Patients admitted to the Intensive Care Unit (ICU) often have multiple physiological abnormalities that require continuous monitoring of hemodynamic, respiratory, neurological, metabolic, and organ function parameters. Each ICU patient can generate millions of data points daily from bedside monitors, mechanical ventilators, infusion pumps, laboratory results, medical imaging, and electronic medical records. The volume and complexity of these data can exceed clinicians' ability to interpret them optimally within a short time. This makes the ICU one of the most suitable healthcare settings for AI applications.[3-4,7-8,10]

Unlike conventional monitoring systems, which are mainly reactive, AI enables continuous predictive monitoring that can detect abnormal physiological patterns before overt clinical deterioration occurs. By using machine learning and deep learning algorithms, AI can integrate multiple data sources simultaneously, helping intensivists identify patients at risk of clinical worsening, estimate treatment responses, and make faster, more objective decisions.[3,7,9,11]

Sepsis is a major cause of morbidity and mortality in the ICU. Delays in diagnosis and antibiotic therapy increase the risk of multiorgan failure and death. Accordingly, many studies are developing AI algorithms to detect sepsis before patients meet conventional clinical criteria. Machine learning models can integrate changes in vital signs, laboratory results, inflammatory markers, vasopressor requirements, and clinical history to predict sepsis risk several hours before clinicians establish the diagnosis. This approach enables earlier initiation of fluid resuscitation, microbiological cultures, and antimicrobial therapy, potentially improving clinical outcomes.[3,7-8]

In addition to early detection, AI is also used to identify sepsis phenotypes, which are groups of patients with different biological characteristics that allow for the application of more individualized therapies (precision critical care). This approach is expected to be one of the main directions of ICU development in the coming decade.[3-4,7]

Acute Kidney Injury (AKI) is a common complication in critically ill patients and is associated with increased mortality, renal replacement therapy, and longer ICU stays. Acute Kidney Injury diagnosis based on rising serum creatinine or reduced urine output is often delayed because these changes usually appear after kidney injury has progressed. Various AI models have been developed to predict AKI by integrating demographic data, comorbidities, nephrotoxic drug exposure, hemodynamic parameters, fluid balance, laboratory findings, and kidney biomarkers. Compared with conventional approaches, ML algorithms can detect complex patterns that precede AKI, enabling earlier preventive interventions.[3,7-9] Despite showing good predictive performance in various studies, most models still require external validation in more diverse populations before they can be routinely implemented in clinical practice.[3-7]

Mechanical ventilation is the main treatment for acute respiratory failure, but suboptimal ventilator settings can increase the risk of ventilator-induced lung injury (VILI). Artificial Intelligence is being developed to help identify the most appropriate ventilation parameters based on each patient's physiological characteristics. By integrating ventilator data, blood gas analysis, pulmonary mechanics, and hemodynamic parameters, AI algorithms can provide individualized recommendations for positive end-expiratory pressure (PEEP), tidal volume, inspired oxygen fraction (FiO_2), and weaning strategies. This approach may reduce lung injury related to mechanical ventilation and improve extubation success. In addition, AI is increasingly used to predict extubation failure by combining respiratory parameters, diaphragmatic function, neurological status, and patient characteristics, helping clinicians determine the most appropriate timing for extubation.[3,7-9,11]

Mortality prediction is one of the most extensively studied AI applications in the ICU. Various machine learning algorithms have outperformed conventional scoring systems, such as the Acute Physiology and Chronic Health Evaluation (APACHE) II, Sequential Organ Failure Assessment (SOFA), and Simplified Acute Physiology Score (SAPS), particularly because AI can dynamically update predictions as a patient's condition changes over time. Beyond mortality estimation, AI can also predict the development of multiple organ dysfunction syndrome (MODS), the need for vasopressors or kidney replacement therapy, and ICU length of stay. These predictions can help intensivists communicate prognosis, allocate resources more efficiently, and prioritize treatment for high-risk patients.[3,7,9-10] However, experts emphasize that mortality prediction models should not be used as the sole basis for limiting life-sustaining treatment. Clinical decisions must still consider the patient's overall condition, patient and family values, and the physician's professional judgment.[4,18]

The Smart ICU concept is one of the latest developments in intensive care, integrating AI, electronic medical records, monitoring devices, the Internet of Medical Things (IoMT), and cloud computing into an interconnected system. In this system, AI functions not only as a prediction tool but also as a continuous clinical decision support system that can analyze patient data in real time, provide early warnings, detect physiological changes, and offer therapeutic recommendations based on current scientific evidence.[4,8-10]

This approach may reduce alarm fatigue, improve healthcare workers' efficiency, accelerate responses to emergencies, and support more precise ICU care. However, successful Smart ICU implementation depends on information system interoperability, data quality, cybersecurity, and workforce readiness.[3,7,14] Despite rapid advances, AI implementation in ICUs still faces several challenges. Most algorithms are developed from retrospective data in academic hospitals in high-income countries and may not perform equally well in other populations. Variations in monitoring devices, treatment protocols, electronic medical record quality, and patient characteristics can also affect AI model accuracy.[3,7,10]

Another challenge is explainability, or an AI system's ability to justify its recommendations. Limited transparency can reduce clinicians' trust and hinder adoption in routine practice. Therefore, developing Explainable Artificial Intelligence (XAI) has become a research priority to ensure that AI recommendations are understandable, verifiable, and clinically and ethically accountable.[11,17-18] In developing countries such as Indonesia, AI implementation in ICUs should proceed gradually through medical record digitization, standardized ICU documentation, development of a national registry for critically ill patients, and creation of AI models based on local data. This approach would improve algorithm validity and support independent AI development that reflects the characteristics of Indonesia's healthcare system.

Generative Artificial Intelligence dan Large Language Models dalam Anestesiologi

The development of Artificial Intelligence (AI) has accelerated markedly with the emergence of Generative Artificial Intelligence (Generative AI) and Large Language Models (LLMs). Unlike conventional machine learning algorithms, which are mainly used for classification or numerical prediction, LLMs are designed to understand, generate, and process natural language through transformer architectures trained on billions of words from diverse sources. This capability allows LLMs not only to produce coherent text but also to perform contextual reasoning, summarize information, translate language, and support scientific literature analysis. In recent years, these advances have drawn increasing attention from the anesthesiology community because of their potential to support clinical practice, education, research, and healthcare management.[4,6,12-13]

In contrast to predictive AI which focuses on analyzing patients' physiological data, LLMs are more of a knowledge assistant that helps doctors access, organize, and present medical information quickly. Therefore, the implementation of LLMs in the field of anesthesiology is more directed as augmented intelligence, which is a technology that increases the productivity and quality of clinical decision-making without replacing the professional responsibilities of doctors.[4:12-13]

Utilization of Large Language Models in Anesthesiology Education

Medical education is among the fields most rapidly adopting LLMs. Tools such as ChatGPT,

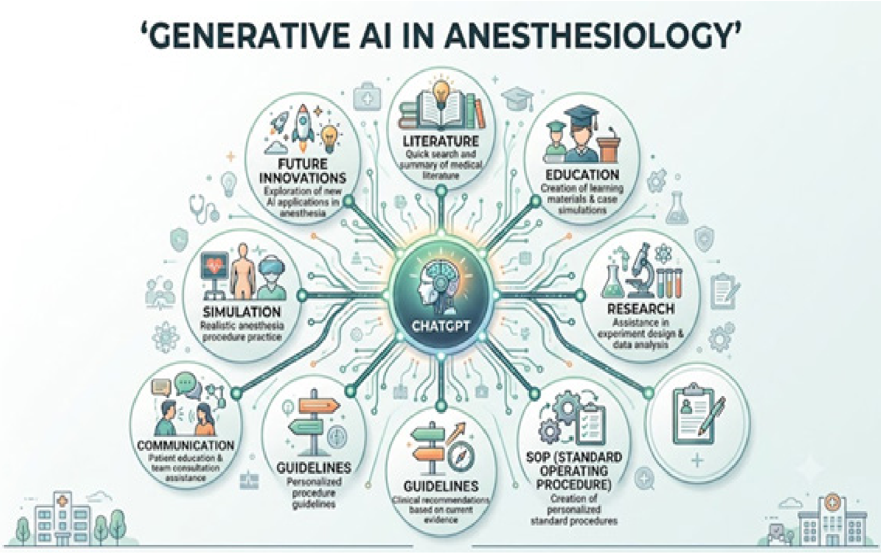

Figure 4. Generative AI in Anesthesiology

Gemini, Claude, and Microsoft Copilot can generate clear explanations of physiology, pharmacology, and anesthesia concepts that are adaptable to learners' levels of competence. LLMs can also support the development of learning objectives, multiple-choice questions, objective structured clinical examination (OSCE) materials, simulation scenarios, and case-based discussion content.[12-13]

For participants of the Anesthesiology Specialist Physician Education Program (Program Pendidikan Dokter Spesialis/PPDS), LLMs can also be used to accelerate literature review, compile scientific article summaries, explain statistical concepts, assist in the interpretation of clinical guidelines, and provide feedback on the quality of scientific writing. However, the results provided by LLMs still require verification using primary literature because this model can still produce inaccurate information (hallucinations).[12-13]

In anesthesiology research, LLMs is beginning to be used to help various stages of research, ranging from topic identification, preparation of research questions, development of literature search strategies, to preparation of manuscript frameworks. In addition, LLMs is able to help researchers improve scientific grammar, improve the readability of manuscripts, prepare abstracts, and produce article summaries in a much shorter time than conventional methods.[12-13] However, various scientific organizations affirm that LLMs should not be used as a scientific source nor listed as an author because it does not have academic responsibility and is unable to account for the content of the manuscript produced. All AI output results must be critically examined by the author, including the validity of references, the accuracy of data interpretation, and conformity with the latest scientific evidence.[4,13]

One of the biggest burdens in modern anesthesia practice is medical documentation. The anesthesiologist must compile preoperative records, intraoperative anesthesia records, postoperative reports, and documentation in the ICU which takes quite a lot of time. LLMs offer the opportunity to automate some of those processes through Natural Language Processing (NLP) technology.

By utilizing data from electronic medical records, LLMs can help compile clinical summaries, create structured anesthesia reports, generate patient discharges, and prepare other administrative documentation. This implementation has the potential to reduce the administrative burden so that doctors have more time to interact directly with patients. However, all documents produced must still be reviewed and approved by the doctor in charge before being included in the official medical record.[12-13] Although LLM capabilities

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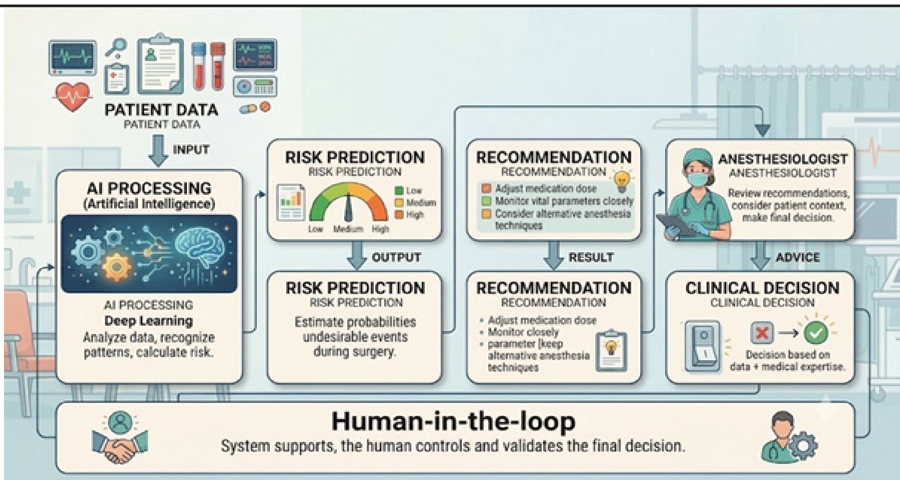

Figure 5. Clinical Decision Support System

are evolving rapidly, their use as a clinical decision support system (CDSS) is still a matter of debate. In contrast to predictive algorithms developed using specific physiological data, LLMs generate answers based on language patterns learned during the training process and do not always have access to the patient's clinical data in real-time. Therefore, the resulting recommendations should not be considered a final medical decision.

In anesthesiology practice, LLMs are best used to explain treatment options based on clinical guidelines, summarize current scientific evidence, or suggest alternative diagnoses for physician verification. This approach aligns with the human-in-the-loop concept, in which all clinical decisions remain under the control of healthcare professionals.[4,12-13]

Limitations and Risks of Using Large Language Models

Despite their considerable potential, LLMs present several challenges. A major limitation is hallucination, in which the model generates information that appears plausible but is not supported by scientific evidence. In anesthesiology, this can be dangerous if AI-generated recommendations are used without clinician verification.[12-13]

nother problem is the limited transparency of the algorithm (black-box phenomenon), so users often do not know the reasoning basis used by the model in generating an answer. In addition, there are concerns about algorithmic bias, the security of patient data, privacy violations, copyright, and the use of medical information that does not comply with the latest clinical guidelines.[4,6,13]

Table 2. Summary of the Role of Large Language Models in Anesthesiology

Field	Potential Utilization	Limitations
Education	Modules, PPDS questions, simulations, Objective Structured Clinical Examination (OSCE), summary of guidelines	Risk of inaccurate information
Research	Literature review, manuscript preparation, language editing	Cannot be an author, references must be verified
Documentation	Medical summary, anesthesia report, administration	Still requires a doctor's validation
Clinical Decision Support	Summary of guidelines, alternative diagnosis, education	Cannot replace clinical results
Administration	Standard Operating Procedure (SOP), accreditation, quality report	Depending on the quality of the input (prompt)

Professional organizations emphasize that LLMs use should follow responsible AI principles, including patient safety, transparency, fairness, personal data protection, and professional accountability. In this context, AI should be regarded as a tool for improving work efficiency rather than a substitute for anesthesiologists' clinical competence.[4,6]

Implementation Opportunities in Indonesia

In Indonesia, the use of Generative AI in anesthesiology is still in its early stages, but it has huge prospects. The initial implementation can be focused on areas that have low clinical risk but provide high benefits, such as the preparation of educational materials, the development of PPDS learning modules, the preparation of standard operating procedures (SOP), literature review, hospital quality documentation, and the preparation of research proposals. This approach allows healthcare institutions to reap the benefits of AI without requiring complex infrastructure investments.

For clinical use, implementation should be carried out gradually through integration with electronic medical records, validation of the Indonesian population, and the drafting of national regulations governing AI governance in health services. Collaboration between professional organizations, educational institutions, hospitals, and the government will be the key to the successful development of AI that is safe, effective, and in accordance with the needs of Indonesia's health system.

The development of Artificial Intelligence (AI) in anesthesiology and intensive care is expected to accelerate over the next decade. While early AI applications have primarily focused on predictive analytics, future systems are likely to integrate multiple clinical data sources simultaneously to support more precise decision-making. The concept of precision perioperative medicine is expected to become a central paradigm in future anesthesia care, enabling therapy to be tailored to each patient's physiological profile, genetic characteristics, biomarkers, and individual treatment responses.[4,6,9-10] One important direction in AI development is multimodal artificial intelligence, which integrates multiple data types simultaneously, including numerical data, physiological signals, medical imaging, electronic medical records, laboratory results, and natural language. Compared with models that rely on a single data type, multimodal AI provides a more comprehensive understanding of a patient's condition, thereby improving the accuracy of predictions and clinical recommendations.[4,6]

In anesthesiology, the integration allows AI to analyze arterial pressure waves, electrocardiography, electroencephalography, capnography, mechanical ventilation, ultrasound results, as well as the patient's disease history simultaneously to generate more individualized recommendations. In critical patients in the ICU, this approach has the potential to improve the ability to detect early organ failure, predict response to therapy, and optimize the use of intensive care resources.[3,8-9]

Another important development is the refinement of closed-loop anesthesia systems, automated systems that adjust intravenous anesthetics, vasopressors, fluids, and mechanical ventilation based on real-time physiological data. These systems are expected to maintain hemodynamic stability and anesthesia depth more consistently than manual control. Although early studies show promising benefits, widespread implementation still requires large-scale prospective clinical trials to confirm safety, reliability, and effects on long-term patient outcomes. In addition, these systems must include a human override mechanism so anesthesiologists can take control when necessary.[8-11]

As artificial intelligence algorithms become increasingly complex, Explainable Artificial Intelligence (XAI) is expected to become a standard requirement in the development of healthcare applications. XAI aims to clarify the rationale behind AI-generated recommendations so clinicians can understand how decisions are made. In anesthesiology practice, XAI can strengthen clinicians' trust in AI systems, facilitate clinical audits, and support ethical and medicolegal accountability. Future algorithms must therefore provide not only high accuracy but also clear explanations that physicians can easily interpret.[11,17-18]

Most experts agree that the future of AI in healthcare is not to replace doctors, but rather to build collaboration between human intelligence and artificial intelligence. Topol introduced the concept of high-performance medicine, which is a healthcare service model that combines AI analytical capabilities with empathy, communication, clinical experience, and ethical considerations owned by health workers.[4] In anesthesiology, AI has the potential to take over repetitive tasks, such as data analysis, monitoring, documentation, and risk prediction, while doctors remain focused on complex decision-making, communication with patients and families, and handling conditions that algorithms cannot predict. This approach is expected to improve patient safety without reducing the central role of the anesthesiologist.[4,6,10]

Anesthesiology professional organizations play a strategic role in preparing for the digital transformation of anesthesia services. Developing AI-use guidelines, algorithm-validation recommendations, data-security standards, and ethical guidance for Generative AI is essential to ensure safe and responsible implementation. Medical education institutions and Anesthesiology Specialist Doctor Education Programs (PPDS) should also begin incorporating core topics such as AI fundamentals, algorithm interpretation, evaluation of scientific evidence, prompt engineering, data security, and ethical considerations into their curricula. This preparation will enable future anesthesiology graduates not only to use AI effectively but also to understand its limitations and critically evaluate each recommendation generated by the system.[12-13,17] Indonesia has a significant opportunity to use AI to improve anesthesia services as surgical volume, critical care demand, and digital health data continue to grow. AI implementation does not need to begin with complex technologies; it can start with digitizing anesthesia documentation, standardizing electronic medical records, establishing national perioperative and ICU registries, and developing evidence-based clinical decision support systems. The phased approach allows for the development of AI that meets national needs, while reducing reliance on algorithms developed from other countries' populations. With the support of government policies, professional organizations, educational institutions, and multidisciplinary collaboration, AI has the potential to become one of the main pillars of the transformation of anesthesiology services in Indonesia in the future.[4,10-11,14]

Conclusion

Artificial Intelligence (AI) has become an innovation that has the potential to transform anesthesiology and intensive care practices through improved risk prediction capabilities, real-time physiological monitoring, clinical decision support system (CDSS), optimization of perioperative management, and the use of Generative AI in education, research, and clinical documentation. However, the implementation of AI still faces challenges in the form of clinical validation, explainability, algorithmic bias, data security, as well as ethical and medicolegal aspects, so AI must be positioned as a support, not a substitute, for clinical decision-making by doctors.

In Indonesia, the implementation of AI needs to be carried out in stages through strengthening digital infrastructure, developing local data-based algorithms, increasing AI literacy of health workers, and drafting regulations that ensure security and accountability. With responsible implementation, AI has the potential to become a strategic partner for anesthesiologists and intensivists in realizing more precise, safe, efficient, and patient-centered perioperative and intensive care services.

Reference

1. Sara Lopes I, Rocha G, Guimarães-Pereira L. Artificial intelligence and its clinical application in Anesthesiology: a systematic review. Journal of Clinical Monitoring and Computing, 2024; 38: 247–259 https://doi.org/10.1007/s10877-023-01088-0.
2. de Filippis R, Al Foysal A. Personalized

Antidepressant Treatment Recommendation Using Reinforcement Learning and Predictive Modelling on Synthetic Patient Data. Open Access Library Journal, 2025; 12: e13957. https://doi.org/10.4236/oalib.1113957.
3. Yoon JH, Pinsky MR, Clermont G. Artificial Intelligence in Critical Care Medicine. Critical Care, 2022; 26:75. https://doi.org/10.1186/s13054-022-03915-3
4. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nat Med, 2024; 30: 1099-1105. doi:10.1038/s41591-024-02957-1.
5. Esteva A, Robicquet A, Ramsundar B, Kulehov V, DePristo M, Chou K, Cui C, Corrado G, et al. A guide to deep learning in healthcare. Nat Med, 2021; 27: 1324-1335. doi:10.1038/s41591-021-01434-9.
6. Rajpurkar P, Chen E, Banerjee O, Topol EJ. AI in health and medicine. Nat Med, 2022; 28: 31-38. doi:10.1038/s41591-021-01614-0.
7. van de Sande D, van Genderen ME, Huiskens J, Gommers D, van Bommel J. Moving from bytes to bedside: a systematic review on the use of artificial intelligence in the intensive care unit. Intensive Care Med, 2021; 47(7): 750-760. doi:10.1007/s00134-021-06446-7.
8. Shu X, Zhu Y, Liu X, Li Y, Yi B, Wang Y. Applications of artificial intelligence in anesthesiology. Anesthesiol Perioper Sci, 2025; 3: 48. doi:10.1007/s44254-025-00131-4.
9. Fei Q, Zhang Y, Liu C, Zheng J, Fu Q. Artificial intelligence in anesthesia and perioperative medicine. Anesthesiol Perioper Sci, 2025; 3: 24. doi:10.1007/s44254-025-00107-4.
10. Han L, Char DS, Aghaeepour N, Stanford Anesthesia AI Working Group. Artificial intelligence in perioperative care: opportunities and challenges. Anesthesiology, 2024; 141(2): 379-387. doi:10.1097/ALN.0000000000005013.
11. Cascella M, Innamorato MA, Simonini A. Recent advances and perspectives in anesthesiology: toward artificial intelligence-based applications. J Clin Med, 2024; 13(15): 4316. doi:10.3390/jcm13154316.
12. Zhu Y, Shu X, Liu X, Li Y, Yi B, Ma D. Applications and challenges of large language models in anesthesiology: narrative review and future perspectives. Anesthesiol Perioper Sci, 2025 ;3: 62. doi:10.1007/s44254-025-00156-9.
13. Daccache N, Zako J, Morisson L, Laferrière-Langlois P. The applications of ChatGPT and other large language models in anesthesiology and critical care: a systematic review. Can J Anaesth, 2025; 72(6): 904-922. doi:10.1007/s12630-025-02973-9.
14. Dost B, Turan EI, Aydın ME, Ahıskalıoğlu A, Narayanan M, Yılmaz R, De Cassai A. Artificial intelligence in anaesthesiology: current applications, challenges, and future directions. Turk J Anaesthesiol Reanim, 2025; 53(6): 282-292. doi:10.4274/TJAR.2025.252320.
15. Baur D, Gehlen T, Scherer J, Back DA, Tsitsilonis S, Kabir K, Osterhoff G. Decision support by machine learning systems for acute management of severely injured patients: A systematic review. Front. Surg, 2022; 9: 924810. doi: 10.3389/fsurg.2022.924810.
16. Chen M, Zhang B, Cai Z, Seery S, Gonzalez MJ, Ali NM, Ren R, et al. Acceptance of clinical artificial intelligence among physicians and medical students: A systematic review with cross-sectional survey. Front. Med (Lausanne), 2022; 9: 990604. doi: 10.3389/fmed.2022.990604
17. Kloka JA, Holtmann SC, Nürenberg-Goloub E, Piekarski F, Zacharowski K, Friedrichson B. Expectations of anesthesiology and intensive care professionals toward artificial intelligence: observational study. JMIR Form Res, 2023; 7: e43896. doi:10.2196/43896.
18. Liu T, Duan Y. Beware the self-fulfilling prophecy: enhancing clinical decision-making with artificial intelligence. Crit Care, 2024; 28: 276. doi:10.1186/s13054-024-05062-3.
19. Kelly CJ, Karthikesalingam A, Suleyman M, Corrado G, King D. Key challenges for delivering clinical impact with artificial intelligence. BMC Medicine, 2019; 17: 195 https://doi.org/10.1186/s12916-019-1426-2.
20. Sendak MP, Gao M, Nichols M, Lin A, Balu S. Machine learning in health care: a critical

appraisal of challenges and opportunities. eGEMs (Generating Evidence & Methods to improve patient outcomes), 2019; 7(1): 1, pp. 1–4. doi: https://doi.org/10.5334/egems.287.
21. Theilen R, Kramer T, Scharffenberg M, Jung IC, Zerlik M, de Abreu MG, Sepehr S, et al. Perceptions on artificial intelligence among anaesthesia and intensive care professionals: An international survey on attitudes, expectations and needs. Journal of Clinical Monitoring and Computing, 2026 https://doi.org/10.1007/s10877-026-01464-6.
22. Shimada K, Inokuchi R, Ohigashi T, Iwagami M, Tanaka M, Gosho M, Tamiya N. Artificial intelligence assisted interventions for perioperative anesthetic management: a systematic review and meta analysis. BMC Anesthesiology, 2024; 24: 306 https://doi.org/10.1186/s12871-024-02699-z.
23. Mehta D, Gonzalez XT, Huang G, Abraham J. Machine learning-augmented interventions in perioperative care: a systematic review and meta-analysis. Br J Anaesth, 2024; 133(6): 1159-1172. https://doi.org/10.1016/j.bja.2024.08.007.