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Review

Transformative Landscape of Anesthesia Education: Simulation, AI Integration, and Learner-Centric Reforms: A Narrative Review

Nobuyasu Komasawa [1,2]

[1] Community Medicine Education Promotion Office, Faculty of Medicine, Kagawa University, Kagawa 761-0793, Japan; komasawa.nobuyasu@kagawa-u.ac.jp
[2] Department of Medical Education, Faculty of Medicine, Kagawa University, Kagawa 761-0793, Japan

Abstract: This article examines the intersection of simulation-based education and the AI revolution in anesthesia medicine. With AI technologies reshaping perioperative management, simulation education faces both challenges and opportunities. The integration of AI into anesthesia practice offers personalized management possibilities, particularly in preoperative assessment and monitoring. However, the ethical, legal, and social implications necessitate careful navigation, emphasizing patient data privacy and accountability. Anesthesiologists must develop non-technical skills, including ethical decision-making and effective AI management, to adapt to the AI era. The experience-based medical education (EXPBME) framework underscores reflective learning and AI literacy acquisition, fostering lifelong learning and adaptation. Learner-centered approaches are pivotal in anesthesia education, promoting active engagement and self-regulated learning. Simulation-based learning, augmented by AI technologies, provides a dynamic platform for technical and non-technical skills development. Ultimately, by prioritizing non-technical skills, embracing learner-centered education, and responsibly leveraging AI technologies, anesthesiologists can contribute to enhanced patient care and safety in the evolving perioperative landscape.

Keywords: anesthesiologist; experience; artificial intelligence; non-technical skill; self-regulated learning

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1. Simulation in Anesthesia Education: Navigating Challenges and Embracing Future Prospects in the AI Era

In recent scholarly works, simulation in the field of health care has been described as "any technology or process that recreates a contextual background, allowing learners to encounter success, make errors, receive feedback, and build confidence within a secure setting" [1,2]. One of the noteworthy advantages of simulation is its ability to offer practical exposure to uncommon clinical crisis situations in the operating room, requiring proficiency in clinical management [3,4].

At present, the widespread adoption of simulation education methods has led to the development and practical examples of various simulation education initiatives, including multidisciplinary collaboration, intra-hospital medical safety promotion, and perioperative management teams [5,6]. The contributions of simulation education in anesthesia medicine, such as "improving medical safety", "activating education on invasive procedures", and "promoting multidisciplinary collaboration", are significant [7].

The arrival of an information-driven society with a foundation in data science and AI is causing significant changes in the field of medicine. The innovative transformation of the medical system is inevitable, leading to continuous changes in the roles of medical systems and healthcare providers [8,9]. Anticipating changes in the ethical or professional aspects of healthcare providers' actions based on the overall perspective of society, it is essential for medical societies and educational institutions to share information and cooperate for the training of healthcare professionals, including those capable of adapting to the AI era [10].

With the advent of AI era, new forms of education, such as Information and Communication Technology (ICT) materials and remote learning, have been introduced as part of the new normal. Additionally, the significant restriction of in-person simulations due to the COVID-19 pandemic is expected to have a substantial impact on the digital transformation of simulation education. In the current rapidly changing landscape, simulation in anesthesia medicine is experiencing an unprecedented period of transformation [11].

The current AI with advanced analytical capabilities through deep learning has begun to bring about innovative changes, even in perioperative management [12,13]. Anesthesiologists entering the era of AI need to develop non-technical skills, including clinical judgment skills related to risk management, not only to maximize the benefits of AI but also to address potential challenges. Third-generation AI, through its sophisticated algorithms referring to neural networks, can engage in complex tasks comparable to human cognitive functions [14]. This includes intricate processes such as reasoning, pattern recognition, data analysis, discovery of hidden insights within vast datasets, and learning from previous experiences. By effectively mimicking these higher-order cognitive functions, AI can significantly contribute to medical research, diagnosis, treatment planning, and predictive modeling.

Given the current circumstances, a research question arises: "How can anesthesiologists adapt to the AI revolution in anesthesia medicine, particularly in terms of personalized management through advanced preoperative assessment and monitoring integration, and what non-technical skills are expected of them in managing AI effectively?" This review aims to provide an overview of the challenges and future prospects of simulation in anesthesia education in the AI era.

2. AI Revolution in Anesthesia Medicine: Personalized Management through Advanced Preoperative Assessment and Monitoring Integration

The rapid integration of information by AI has been continuously impacting clinical settings, with anesthesia medicine being no exception. Among the effects that AI is beginning to have on anesthesia medicine, the first two are (1) preoperative risk assessment support and (2) innovative monitoring through information integration [15]. In addition to preoperative risk assessment and monitoring, the potential for AI to integrate and analyze past patient information (e.g., anesthesia or procedural sedation history) and pathophysiological data could lead to personalized anesthesia management [16,17].

Firstly, concerning preoperative risk assessment support, AI can provide valuable information for patient pre-assessment. In other words, by summarizing electronic medical record information such as preoperative tests, AI may offer optimal recommendations for anesthesia management. When an anesthesiologist is planning a patient's treatment, AI can provide the latest clinical guidelines and medical literature, supporting decision-making by suggesting anesthesia techniques and raising awareness of contraindicated medications [18].

Next, we discuss the innovation in monitoring through AI-driven information integration and analysis. Currently, many monitors automatically analyze parameters like respiratory rate and electrocardiogram waveforms, alerting us to potential abnormalities. Anesthesia monitoring alarms are currently based on individual values such as blood pressure and percutaneous oxygen saturation, but systems such as arterial pressure cardiac output measurement have been introduced, estimating vascular volume from calculated values [19,20]. However, there are challenges in the current stage regarding the integration of various information. With further development of AI, these multiple monitoring sources could be integrated to provide specific pathophysiological information, such as "greater than 30% likelihood of pulmonary thromboembolism", "25% likelihood of septic shock after operation" or "35% likelihood of progressing peripheral circulation collapse" potentially contributing to the prevention of fatal complications.

The integration of preoperative information and monitoring, including patient conditions and pathophysiology, may lead to personalized anesthesia management [21]. With the accumulation of big data during the perioperative period, verification of individual patient age, gender, test results, pathophysiology, and surgical procedures could potentially lead to the provision of anesthesia protocols tailored to each patient and their condition [22].

Additionally, by incorporating patient test values with past anesthesia history and sedation history data, a further reduction in risk may be possible. AI could provide recommendations that cannot be explained by current clinical trials or drug mechanisms. Machine learning is a subset of AI that focuses on creating algorithms and models capable of learning patterns from data and making predictions or decisions without explicit programming. It involves techniques like supervised learning, unsupervised learning, and reinforcement learning to train models to improve performance over time. However, deep networks do not "think" or access a database of clinical knowledge. These networks are trained with extensive datasets to recognize patterns, yet they lack the ability to justify their suggestions. Similarly, Large Language Models such as ChatGPT can offer recommendations, but they are unable to cite the sources of their knowledge [23].

Currently, many facilities have introduced electronic anesthesia records in addition to electronic medical records. If AI's advanced analytical capabilities can be applied, the personalization of anesthesia management is predicted to advance innovatively. From this perspective, AI combined with telemedicine may provide support for anesthesia and perioperative management in regional healthcare and disaster medicine fields [23].

3. Non-Technical Skills Regarding "AI Management" Expected of Anesthesiologists

Certainly, the utilization of AI in healthcare brings not only benefits but also associated risks. Firstly, the introduction of AI entails ethical, legal, and social issues (ELSI), such as ethical and legal challenges related to privacy rights and personal information management [24]. Additionally, diagnostic assistance and clinical decision support provided by AI are not always accurate. Therefore, non-technical skills to control AI, especially the ability to recognize the deficiencies and risks of AI, are likely to become a fundamental competency expected of anesthesiologists in the future.

For example, patients need to understand how their data are utilized and provide consent accordingly. Moreover, questions arise regarding the responsibility and accountability of AI systems when intervening in surgery [25]. These systems may be subject to regulation as medical devices, necessitating proper testing, certification, and surveillance. Legal liability in case of system malfunctions must also be addressed. Additionally, safeguarding patient data and privacy is essential under appropriate legal frameworks. Adoption of AI-assisted surgical systems may widen healthcare disparities if they require advanced technology and facilities, highlighting the need to improve access and education. Furthermore, AI intervention may alter the roles and skill requirements of healthcare professionals, prompting adjustments in education and training. Continued discussions and ethical framework establishment are imperative to balance the potential benefits and risks of AI integration in healthcare.

Anesthesiologists in the AI era should be aware of the potential risks of AI and emphasize the ongoing importance of non-technical skills in controlling AI. In the rapidly changing landscape of the AI era, the significance of both technical and non-technical skills in medical practice is undeniable.

For example, there are several risks associated with using AI's Large Language Model (LLM) for communication with patients. For example, AI may provide inaccurate information, particularly in the case of medical information, which could lead to incorrect advice or diagnoses. Additionally, AI lacks emotions and ethical judgment, making it difficult to appropriately respond to individual patient situations and emotions. Furthermore, concerns about privacy and security arise as patient personal information is involved. AI should play a complementary role rather than a substitute for healthcare professionals, with human judgment and supervision being crucial. The development and implementation of AI should adhere to ethical guidelines and legal regulations. It is important for human healthcare professionals to carefully verify the information provided by AI in communication with patients.

In summary, the use of AI in anesthesia medicine has the potential to contribute to the improvement of anesthesia quality, such as patient outcomes and safety enhancement. However, there is a need to cultivate non-technical skills to control AI. How to develop non-technical skills, particularly in AI management, is an urgent challenge for all anesthesiologists.

4. Cultivating Non-Technical Skills for AI Management in Healthcare: The Experience-Based Medical Education (EXPBME) Educational Framework

Training anesthesia residents in crisis management and resuscitation skills within the operating room is crucial for the development of fundamental competencies. Instances like intraoperative massive hemorrhage and hypoxia during anesthesia induction highlight the necessity for anesthesiologists to possess crisis management and clinical skill competencies. Achieving optimal survival rates and prognosis for patients in crisis situations within the operating room demands that anesthesiologists not only excel in technical skills but also acquire advanced non-technical skills, especially in leadership functions [26]. The significance of non-technical skills has been emphasized in both medical education and patient safety programs. These skills encompass a range of abilities beyond technical expertise, including "situation awareness", "decision-making", "effective communication", and "stress management." Despite the remarkable progress in medical technology, the enduring importance of non-technical skills remains evident [27]. Non-technical skills such as "situation awareness", "decision-making", "effective communication", and "stress management" are crucial elements for individual and team success. These skills are further enhanced by the evolution and integration of AI. For example, situation awareness involves understanding the surrounding environment and accurately assessing information. AI aids in revealing the situation by collecting and analyzing real-time data from sensor data, big data, and other sources. Decision-making is the process of choosing the best course of action based on available information. AI can complement complex decision-making processes by analyzing vast amounts of data. For instance, in business decision-making, AI analyzes market trends and competitors' behavior to provide decision-making support to executives. Effective communication is the ability to convey information clearly and effectively. AI enables communication with humans using natural language processing and speech recognition technologies. For example, smart speakers and chatbots understand human language and generate appropriate responses. Stress management involves the ability to cope with pressure and stress. AI supports humans by handling routine tasks and simple work, allowing them to focus on more complex tasks. Additionally, AI reduces stress by automating tasks and reducing human workload. These non-technical skills remain important in interaction with AI. AI can complement these skills and function as a tool for achieving more effective outcomes collaboratively with humans.

Consequently, with the integration of new AI technology into the healthcare landscape, the development of non-technical skills for AI management becomes equally indispensable for anesthesiologists. This shift is essential to enable effective patient care by assimilating and interpreting the substantial volume of AI-generated data. Even though AI offers comprehensive information and recommendations, it is the responsibility of the anesthesiologist to assess the appropriateness of these suggestions.

To cultivate non-technical skills, thorough "experience" and learning from it are necessary. In the development of non-technical skills related to AI management, it is unquestionably essential to build learning on the theory of experiential learning, emphasizing "experience with AI" and reflective learning. Healthcare professionals will make clinical judgments based on non-technical skills founded on a diverse range of "experiences with AI". Various reports suggest the importance of non-technical skills for feeling uncertainty and detecting failure associated with AI [25–27].

The author believes that in the AI era, learning through a thorough reflection on "experience" in clinical settings and simulation environments is crucial, proposing the educational framework of "experience-based medical education (EXPBME)" [28]. In other words, in clinical and simulation environments, adopting a learning attitude that prioritizes experience and its reflection through EXPBME can effectively cultivate non-technical skills for AI management. Furthermore, being mindful of the EXPBME educational framework based on experience in medical professional education in the AI era is crucial for fostering non-technical skills from the perspective of future healthcare professionals.

Within the framework of EXPBME, acquiring AI literacy and cultivating non-technical skills for AI management are indispensable. Additionally, within the EXPBME framework, self-directed learning, or in other words, active learning self-management, will be required to explore how to gain sufficient learning from experience.

5. Integrating Experiential Learning: Bridging Simulation Education and Clinical Training in Anesthesia Specialization

As mentioned previously, simulation education and clinical education both share the foundational principles of experiential learning theory. In this approach, learners acquire experiences either through simulations or in actual clinical settings, reflect on those experiences, and gain new knowledge. Clinical education exposes learners to real-life clinical environments, while simulation environments provide simulated experiences. After thoughtful reflection on these experiences, learners are guided toward actions that contribute to the development of new competencies.

NOTECHS and Anesthesiologists' Non-Technical Skills (ANTS) were developed for surgical team non-technical skills [29,30]. The Oxford NOTECHS scale was developed from an aviation instrument for the assessment of non-technical skills. The ANTS are behaviors that an anesthesiologist exhibits in an operating room environment that are not directly related to drugs, equipment, and medical expertise. However, I believe these systems may not fully cover factors relevant to anesthesiologist education in the AI era.

Overcoming this drastic change re-evaluation of experiential learning theory is essential. Given the shared foundation of experiential learning theory, the principles of educational engineering in simulation education can be applied effectively to clinical education. The key elements of thorough pre-learning, pre-briefing, and ensuring psychological safety, which are fundamental in simulation education practices, are attitudes that can be beneficial in all teaching scenarios. Positive feedback from supervising physicians, acknowledging a job well done, proves highly effective in bolstering residents' self-esteem and ensuring psychological safety.

Various factors influence the self-regulated learning skills of anesthesia residents, with the residents themselves being a significant factor. While the residents themselves play a crucial role in enhancing their self-regulated learning skills to improve how they learn, mentoring by supervising physicians is also a vital element. Through mentoring by supervising physicians, self-regulated learning skills are nurtured, contributing to the formation of the professional identity of anesthesia residents. The relationship between supervising anesthesiologists and learners significantly influences not only their own lifelong learning but also how learners, once becoming supervising physicians, teach [31]. Therefore, the cultivation of self-regulated learning skills in anesthesia specialization training not only influences the learners' "learning reform" but also impacts "teaching method refinement" for future anesthesiology educators. The influence of self-regulated learning skills on future teaching methods is beneficial from the perspective of "succession of professional skills" among us anesthesiologists.

6. Essential Requirements for "Basic Knowledge" and "Ensuring Psychological Safety" in the AI Era

The potential of AI in simulation-based education for anesthesiologists is wide-ranging. AI can provide real-time feedback and tailored guidance to learners during simulations, detecting their progress and errors swiftly, thus fostering effective learning. Additionally, AI aids in simulating complex scenarios or real-life situations, allowing learners to practice skills and knowledge in environments close to reality. For instance, in medical simulations, AI can simulate patient symptoms and diseases, aiding learners in learning diagnosis and treatment. Moreover, AI can automatically generate customized learning content based on learners' progress and tendencies, enabling them to proceed at their own pace and providing an optimal learning experience.

AI enables real dialogue and collaboration in simulation environments, allowing learners to enhance problem-solving and decision-making skills through interaction with AI. Furthermore, multiple learners can collaborate with AI to learn teamwork skills. Additionally, AI analyzes learners' behaviors and progress, optimizing educational programs by identifying learners' weaknesses and needs and providing individually tailored learning plans, thereby achieving more effective education. By combining these elements, AI enhances the effectiveness and efficiency of simulation-based education, supporting anesthesiology residents in adapting to real-life situations and acquiring practical skills.

Even as educational media and simulators become the new normal, our values, thought processes, and learning processes are unlikely to undergo rapid changes [32]. Despite the development of new simulation education methods, the principle that "learners are the subjects of learning, and active learning involving proactive and interactive deep learning is essential" remains unchanged [33]. Therefore, in the near future of medical education, the primary role expected of educators will likely be to ensure learners' psychological safety and establish an environment conducive to active learning.

Many supervising physicians, except for clinical training supervisor workshops, have not consistently received training on "educational methods". In fact, there is no obligation to participate in training workshops for supervising physicians when applying for approval as a supervising anesthesiologist [34].

Additionally, many educators may be encountering simulation medical education for the first time, especially considering the publicization of student doctors in pre-clinical education, the guidance of early clinical trainees, and involvement in guiding emergency medical technicians [35]. From this perspective, it may be appropriate for the entire society to devise and introduce workshops on educational methods in the critical care field. While simulation education methods are familiar to clinical educators, it is anticipated that mutual reduction with clinical education will accelerate and deepen, leading to the genuine sustainability of both simulation and clinical education.

7. Significance of Learner-Centered EXPBME for Both Clinical and Simulation Education in the AI-Driven Society

The field of anesthesiology is constantly evolving, driven by technological advancements, groundbreaking research, and a changing paradigm in patient care. This dynamic environment places an increasing demand on anesthesiologists to continuously expand their knowledge and refine their skills [36]. Although conventional anesthesia education provides a strong foundational understanding, it falls short of meeting the growing demands and complexities of an AI-driven perioperative environment. To cultivate this competency, emphasizing the concept of learner-centered EXPBME, which encourages deep and thoughtful reflection based on experience, is essential in both clinical and simulation education in an AI-driven society (Figure 1).

To meet the evolving demands of the medical field, anesthesia education must transcend traditional boundaries by utilizing simulation to acquire various non-technical skills in managing AI [37]. Through these learner-centered strategies, we can foster a generation of anesthesiologists prepared to make enduring and meaningful contributions to the ever-advancing realm of the perioperative environment in the AI era. While AI technology brings a complex and sometimes pressing learning environment, there is a possibility of inhibition of active learning. The suppression of active learning by AI refers to hindering learners from actively advancing their own learning. When AI solves problems and provides information on behalf of learners, they may lose opportunities to think about problems and find solutions on their own. This could potentially lead to a decrease in learners' autonomy and creativity. Moreover, excessive reliance on AI by learners may result in a decline in their self-learning and information-processing abilities. If learners rely too heavily on AI without pursuing learning on their own, it could impact the development of problem-solving skills and critical thinking. However, when used appropriately, AI can also support active learning. By answering learners' questions and providing information, AI can help learners progress more efficiently. AI should play a complementary role and be utilized as a means for learners to deepen their own learning. Ultimately, it is important for educators and learners themselves to make appropriate judgments about how to use AI and maintain a balance. AI should be used as a tool to support learners' growth and development. From these viewpoints, simulation-based education in the AI era should shift more 'learner-centered'. In other words, it is the time to focus on 'simulation-based learning'.

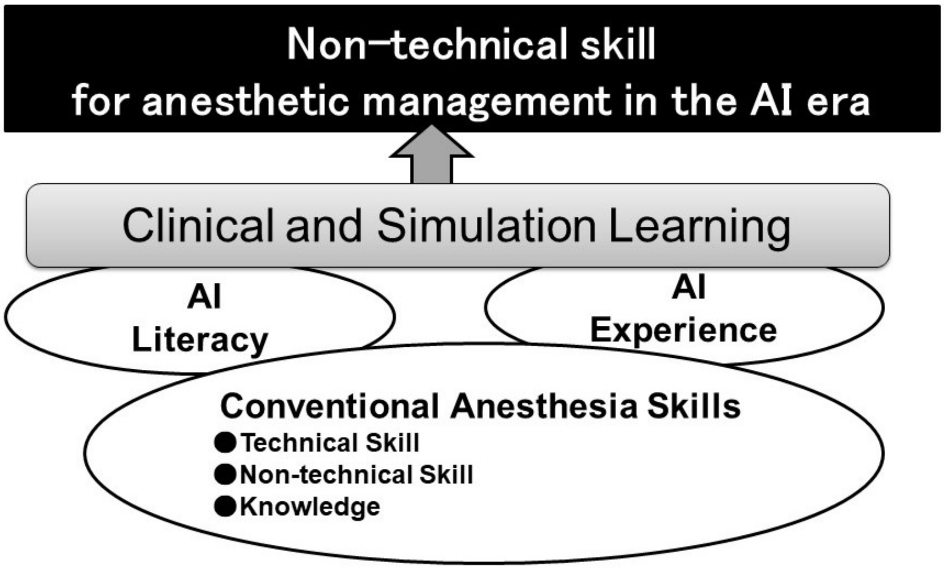

Figure 1. Non-technical skill development for anesthetic management in the AI era.

In medical education institutions, "education" is an unavoidable element where instructional staff is expected to support learners, fostering self-regulated learning skills that enable learners to sustain active learning [38]. However, the impact of workstyle changes has begun to increasingly suppress educational aspects. While attempts to alleviate physicians' burdens through AI have progressed, the ongoing debate revolves around the impact of workstyle changes on education [39].

In essence, medical education, irrespective of pre- and post-graduate stages, is expected to undergo significant transformation due to the combined influence of "AI integration in healthcare" and "workstyle changes". In response to these influences, anesthesia medical education faces an urgent need for learner-centric "learning reform" capable of adapting to the AI era. From these viewpoints, the shift from 'simulation-based education' to 'simulation-based learning' is warranted.

Anesthesia residents bring diverse knowledge, skills, and attitudes acquired through experiences until university entrance exams or graduation from medical school. Many anesthesia residents have a certain level of self-regulated learning skills developed during learning experiences. This implies an understanding of one's own learning characteristics and improving the efficiency of learning through the cultivation of self-regulated learning skills. Therefore, medical education institutions are expected to provide support not only for AI literacy education but also for faculty development related to learning methods and instructional approaches.

Even amid rapid changes brought about by AI in perioperative management, the learning process based on the "experience" of anesthesia physicians is likely to remain largely unchanged. Therefore, it is crucial to focus on non-technical skills development within the EXPBME framework, emphasizing AI management skills and AI literacy acquisition (Figure 2).

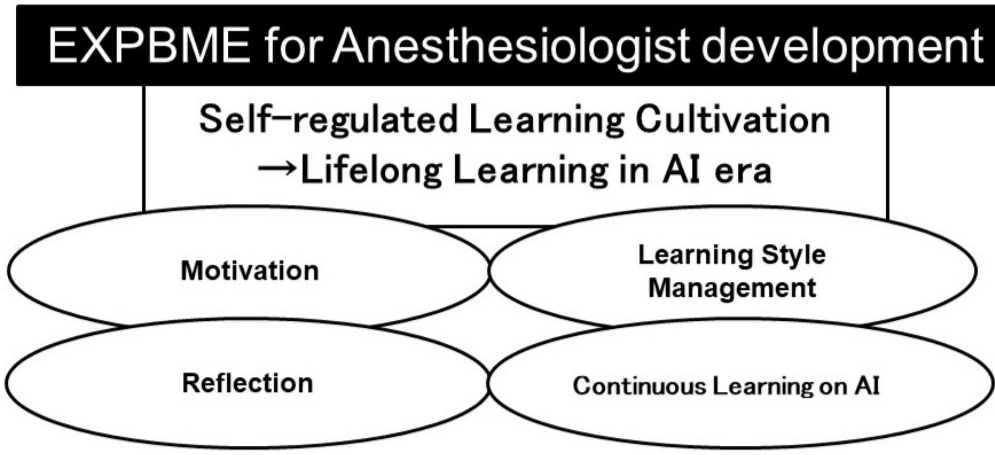

Figure 2. Experience-based medical education for anesthesiologists leads to lifelong learning of anesthesiologists in the AI era.

Learner-centric EXPBME enables anesthesia physicians to appropriately utilize AI in perioperative management and facilitate risk management within the complex and ever-changing field of anesthesia. In the already initiated AI era, educational hospitals that cultivate anesthesia residents are expected to enhance their educational infrastructure, emphasizing self-regulated learning skills. By providing support conscious of learner-centric EXPBME, anesthesia residents can practice a learning reform that leverages self-regulated learning skills while being aware of the image of an anesthesia specialist required in the AI era.

8. Conclusions

In navigating the evolving landscape of anesthesia education amidst the AI revolution, it is imperative to acknowledge the transformative impact of simulation and experiential learning. As AI technologies reshape perioperative management, anesthesiologists must adapt by developing both technical and non-technical competencies.

Simulation education has proven invaluable in providing practical exposure to complex clinical scenarios, fostering multidisciplinary collaboration, and enhancing patient safety. However, the advent of AI introduces new challenges and opportunities. Anesthesiologists must now grapple with integrating AI-driven technologies into personalized management approaches, leveraging advanced preoperative assessment, and monitoring integration. Non-technical skills, particularly those related to AI management, emerge as essential competencies for anesthesiologists. Beyond technical expertise, they must cultivate abilities in ethical decision-making, risk recognition, and patient data privacy protection. Moreover, as AI reshapes healthcare delivery, the role of educators becomes pivotal in ensuring learners' psychological safety and fostering active, learner-centered experiences.

The proposed experience-based medical education (EXPBME) framework emphasizes the importance of reflective learning and AI literacy acquisition. Through learner-centric approaches, anesthesia education can adapt to the demands of the AI-driven society while nurturing self-regulated learning skills essential for lifelong professional growth.

In summary, as anesthesia education transcends traditional boundaries and embraces simulation-based learning, anesthesiologists are poised to navigate the complexities of the AI era. By prioritizing experiential learning, cultivating non-technical skills, and embracing learner-centered education, they can contribute meaningfully to patient care in the dynamic landscape of perioperative medicine.

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