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E-learning for anesthesiology in burn care: A narrative review of current applications and future opportunities

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ABSTRACT

Burn care presents significant clinical challenges, requiring anesthesiologists to possess advanced knowledge and skills in managing complex physiological responses and performing critical interventions. Traditional education models in anesthesiology have relied heavily on in-person teaching and clinical apprenticeship, which often lack flexibility, consistency, and broad accessibility. The rapid expansion of digital learning modalities, accelerated by Coronavirus disease 2019 (COVID-19) pandemic, has positioned e-learning as a transformative tool in medical education. This narrative review explores the current landscape of e-learning in anesthesiology with a particular focus on burn patient management. We review the design and implementation of digital modules for airway control, pain management, fluid resuscitation, and perioperative care in burn settings. Additionally, this study highlights the technological innovations—such as virtual simulations and adaptive learning algorithms—that are enhancing the educational experience. Barriers to implementation, including infrastructure limitations, faculty readiness, and learner engagement, are discussed. Finally, we propose strategic directions for future integration of e-learning into anesthesiology curricula to better prepare clinicians for the unique demands of burn care. Our findings suggest that while e-learning holds considerable promise, targeted development and systematic evaluation are necessary to optimize its impact on clinical competence and patient outcomes in the field of anesthesiology.

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1. Introduction

Burn injuries represent one of the most complex and demanding medical conditions, owing to their multifaceted pathophysiology and the intensive care they necessitate. Severe burns lead to widespread tissue damage, systemic inflammatory responses, and profound metabolic changes, all of which require coordinated multidisciplinary management. Anesthesiology plays a vital role in this continuum of care, addressing essential elements such as airway management, pain control, fluid resuscitation, perioperative monitoring, and temperature regulation [1,2]. Given these complexities, anesthesiology professionals involved in burn care must develop and maintain highly specialized clinical knowledge and procedural skills to ensure safe and effective patient outcomes.

Traditional methods of anesthesiology education—such as didactic lectures, practical workshops, and supervised clinical rotations—offer valuable experiential learning but also present several inherent limitations. These include variability in teaching quality, restricted access to expert faculty, uneven exposure to critical clinical scenarios, and difficulty in maintaining standardized curricula across institutions and regions [3,4]. Moreover, the rigidity of traditional training methods can limit responsiveness to individual learner needs. The global disruptions caused by COVID-19 pandemic further exposed these vulnerabilities and accelerated the adoption of digital and remote education platforms in medical training [5].

E-learning, defined as the delivery of educational content through digital platforms, has emerged as a powerful complement to traditional anesthesiology education. By offering standardized, interactive, and continuously updated content, e-learning provides a flexible and accessible modality that transcends geographical and temporal barriers [6,7].

Digital tools—such as video tutorials, virtual simulations, interactive quizzes, and real-time feedback—can improve learner engagement and knowledge retention. Numerous studies support the effectiveness of e-learning in enhancing procedural competency, clinical decision-making, and theoretical understanding [8,9].

However, the application of e-learning specifically tailored to burn anesthesiology remains relatively underdeveloped. The distinctive challenges of burn care—such as complex pain syndromes, fluid balance intricacies, and specialized airway techniques—demand highly targeted, evidence-informed digital modules. This narrative review aims to synthesize existing literature on the application and effectiveness of web-based education in anesthesiology with a focus on burn patient management. It also explores emerging technologies, implementation barriers, and future directions for integrating e-learning into anesthesiology curricula more effectively.

2. Current Applications of E-learning in Anesthesiology

2.1 Search Strategy and Selection Criteria

Although this is a narrative review and not a systematic review, we adopted a structured approach to identify relevant literature. Databases including PubMed, Scopus, and Google Scholar were searched using keywords such as “e-learning,” “anesthesiology education,” “burn care,” “simulation,” and “digital medical education.” Articles published between 2000 and 2024 were considered.

This timeframe was chosen because most e-learning applications in anesthesiology and burn care have emerged after 2000, reflecting the rapid growth of digital education technologies in the past two decades. We included narrative and systematic reviews, randomized controlled trials, observational studies, and descriptive reports relevant to e-learning in anesthesiology and burn management. Papers not related to medical education, not in English, or focusing exclusively on unrelated specialties were excluded. This approach aimed to ensure a broad yet relevant coverage of the field.

2.2 In Literature Selection

As with all narrative reviews, the potential for selection bias exists. To mitigate this limitation, we attempted to include studies from diverse sources and perspectives. Two authors independently screened and discussed the relevance of the retrieved literature, and disagreements were resolved by consensus. Any disputes during the screening process were resolved by consensus to enhance methodological transparency. Nonetheless, the absence of a formal systematic protocol should be considered when interpreting our findings.

2.3 Quality Assessment of Included Literature

We did not conduct a formal critical appraisal using standardized tools (e.g., the Grading of Recommendations Assessment, Development, and Evaluation (GRADE)), but we gave greater weight to studies that reported empirical outcomes. However, we gave greater weight to studies reporting empirical outcomes (e.g., randomized controlled trials, observational evaluations) when synthesizing evidence on effectiveness. Expert opinion papers and descriptive reports were also included, particularly in areas where high-quality evidence was limited, such as burn-specific anesthesia education. Recurring themes—including current applications, technological innovations, barriers, and future opportunities—were identified through iterative discussion among the authors. These themes were then categorized into major domains to guide the synthesis of evidence and ensure a structured narrative presentation.

2.4 *Overview of Current Applications*

E-learning has increasingly become a central component of anesthesiology education, driven by the need for flexible, standardized, and scalable training tools that meet the demands of modern medical education. Current applications range from web-based modules and virtual simulations to blended learning strategies and mobile learning platforms, each contributing to different dimensions of knowledge acquisition and skill development [7]. One of the most prominent applications of e-learning in anesthesiology is knowledge-based education, where online modules are utilized to teach core concepts, including pharmacology, physiology, anesthetic techniques, and crisis management protocols. These platforms often integrate multimedia tools such as animations, voice-overs, and interactive quizzes, which enhance comprehension and engagement [6,10]. In a meta-analysis by Cook et al., internet-based learning demonstrated significant improvements in knowledge outcomes compared to no intervention and was comparable to traditional teaching methods [7].

Simulation-based e-learning is another critical application, particularly relevant for developing technical and decision-making skills. High-fidelity virtual simulations allow learners to practice complex scenarios—such as difficult airway management, anesthesia for trauma, or intraoperative emergencies—without risk to patients [3,4,11]. For instance, immersive simulation platforms have been shown to enhance learners' performance in procedural tasks, as well as their confidence and preparedness for real-world clinical practice [8,9]. Blended learning, which combines face-to-face teaching with online content, has also gained traction in anesthesiology. This approach allows learners to review theoretical content asynchronously online and engage in hands-on training during in-person sessions, thereby optimizing time efficiency and reinforcing learning through multiple modalities. Maloney et al. demonstrated that a blended learning approach to evidence-based medicine for medical students was more cost-effective than traditional classroom-only instruction, without compromising learning outcomes [12].

Furthermore, e-learning has played a pivotal role in continuing medical education (CME) for anesthesiologists. With increasing demands for lifelong learning and recertification, online CME platforms offer convenient access to updated guidelines, emerging practices, and research developments. These platforms often incorporate modular designs, allowing anesthesiologists to select specific areas of interest and complete accredited courses at their own pace [6,13,14]. Importantly, the COVID-19 pandemic significantly accelerated the adoption of e-learning across medical disciplines, including anesthesiology. Institutions worldwide shifted to virtual platforms for lectures, case-based discussions, and even examinations [5,15]. This rapid transition not only demonstrated the resilience and adaptability of e-learning systems but also highlighted persistent gaps in access, content quality, and learner assessment that require future innovation.

A summary of the main applications of e-learning in anesthesiology is illustrated in Figure 1. As shown, e-learning encompasses a variety of modalities, including knowledge-based education through multimedia-rich online modules, simulation-based training for skill development in complex scenarios, and blended learning approaches that combine digital content with in-person practice. Furthermore, it plays a vital role in CME, offering flexible and modular formats for professional development.

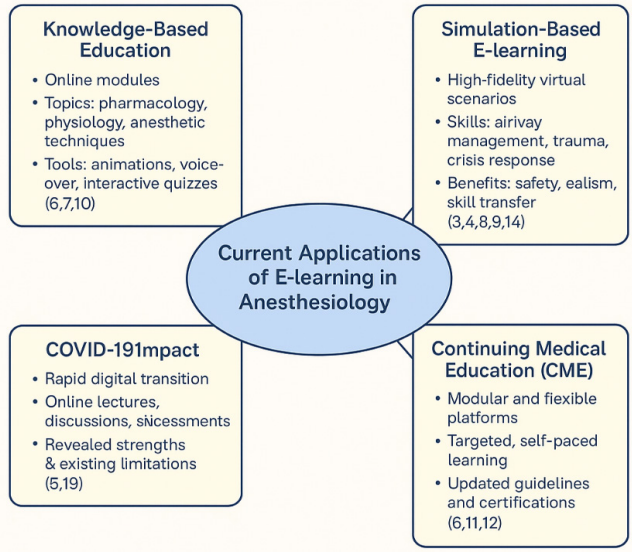

Figure 1. The authors developed the mind map as a conceptual synthesis of the reviewed literature. It integrates key domains consistently identified across included studies—such as current applications, technological innovations, barriers, and future opportunities—and serves as a visual framework for understanding the multidimensional role of e-learning in anesthesiology.

The figure also highlights how the COVID-19 pandemic accelerated the integration of virtual platforms into anesthesiology education, underscoring both the opportunities and challenges of digital learning. This schematic representation provides a concise overview of the evolving landscape of web-based anesthesiology training.

3. Technological Innovations Enhancing E-learning

The rapid evolution of educational technologies has significantly enhanced the potential of e-learning in medical education, particularly in high-stakes fields such as anesthesiology. Innovations in digital platforms, simulation technologies, artificial intelligence, and mobile learning have transformed static online content into dynamic, personalized, and immersive learning environments. One of the most impactful innovations is the integration of high-fidelity virtual simulation and virtual reality (VR). These technologies allow learners to engage in realistic, risk-free clinical scenarios that replicate anesthetic crises such as malignant hyperthermia, airway obstruction, or cardiac arrest. VR-based systems enhance psychomotor skills and decision-making by providing haptic feedback, 3D visualization, and scenario repetition, all of which are essential for developing muscle memory and critical thinking [11,16,17].

Augmented reality (AR), although less widespread, is emerging as a powerful tool for superimposing digital information on real-world clinical environments. This technology has potential applications in procedures such as ultrasound-guided regional anesthesia or central venous catheter placement, where visual-spatial perception is crucial [18]. Intelligent Tutoring Systems (ITS) and adaptive learning platforms, powered by artificial intelligence (AI), can personalize educational pathways by analyzing learner performance and adapting content difficulty accordingly. These systems offer targeted feedback, real-time performance tracking, and customized assessments, making them especially valuable in preparing anesthesiology residents for board exams and competency-based milestones [6,7,13]. Gamification—the application of game design elements such as points, badges, leaderboards, and challenges—has also been adopted in e-learning modules to enhance motivation, participation, and retention. Studies suggest that gamified learning environments are particularly effective in improving procedural knowledge and teamwork in high-stress specialties like anesthesiology [19]. Another transformative innovation is mobile-based learning (m-learning), which leverages the ubiquity of smartphones and tablets. Mobile apps enable on-the-go access to updated protocols, pharmacology databases, quick reference tools, and interactive case studies, facilitating just-in-time learning and decision support in perioperative settings [20]. For example, apps that offer anesthesia dosage calculators, airway management algorithms, or regional block tutorials have become standard tools in both training and clinical practice. Additionally, the use of Learning Management Systems (LMS) such as Moodle, Blackboard, or Canvas enables centralized content delivery, tracks learner progress, facilitates peer discussion, and supports asynchronous education. These systems are essential for organizing modular courses in a structured yet flexible manner, particularly in institutions with limited access to in-person faculty or clinical training sites [5,10,14]. Emerging tele-education technologies have also expanded the reach of expert instruction across institutions and geographic boundaries. Live-streamed workshops, remote supervision via video conferencing, and cloud-based skill assessments allow educators to deliver consistent training to dispersed learner populations—an innovation especially relevant in low-resource settings and during pandemics [5,15].

4. Challenges and Barriers to E-learning Implementation

Despite the growing body of evidence supporting the efficacy of e-learning in medical education, its successful implementation, especially in specialized domains such as anesthesiology and burn care, is met with several challenges. These obstacles span across technological, institutional, pedagogical, and learner-related domains. One significant barrier is the limited infrastructure and access to reliable technology, particularly in low- and middle-income countries or resource-limited healthcare settings. Many institutions still face insufficient internet bandwidth, outdated hardware, or a lack of access to simulation tools and virtual platforms, all of which impair the delivery and engagement of digital learning experiences [5,20].

Another significant issue is the lack of standardized content and quality control. E-learning modules may vary widely in their design, depth, and alignment with evidence-based practices. Without robust guidelines or regulatory oversight, there is a risk that online content may be outdated, clinically inaccurate, or poorly aligned with competency frameworks such as those recommended by anesthesiology accreditation boards [3,4,10]. Faculty resistance and lack of digital literacy also pose notable barriers. Transitioning from traditional, in-person teaching methods to online modalities often requires a paradigm shift in instructional strategies. Many educators may lack the necessary training or motivation to design, deliver, or evaluate practical e-learning modules. Time constraints and insufficient institutional support for e-learning development further exacerbate this issue [6,12].

From a pedagogical perspective, the absence of hands-on experience in purely digital formats is a persistent limitation, especially in a highly procedural field like anesthesiology. While virtual simulations can offer some degree of psychomotor skill training, they may not fully replicate the tactile feedback, stress environment, and interprofessional communication required in real clinical settings [11,19]. This gap is

particularly critical in burn care anesthesia, where precision in airway management, fluid resuscitation, and pain control is essential. Another commonly cited challenge is the limited learner engagement and motivation in self-directed e-learning environments. Without direct instructor interaction and peer collaboration, learners may feel isolated or struggle to maintain consistent study habits. Passive content formats (e.g., long recorded lectures) further reduce retention and fail to foster critical thinking or clinical reasoning skills [8,16].

Assessment and feedback mechanisms within e-learning platforms are often insufficient or poorly integrated. Validated tools for evaluating clinical competencies, especially in virtual settings, are still evolving. Furthermore, there are challenges in ensuring exam integrity, standardizing performance metrics, and offering personalized feedback in scalable ways [7,9,13]. Lastly, privacy and data security concerns arise with the use of online platforms that collect learner information, store patient scenarios, or integrate with hospital systems. Ensuring compliance with medical data protection regulations, such as the Health Insurance Portability and Accountability Act (HIPAA) or the General Data Protection Regulation (GDPR), is essential yet often neglected during rapid e-learning deployment [18]. In conclusion, while e-learning holds great promise in transforming anesthesiology education, including its potential application in burn care training, addressing these multifaceted barriers is essential. Strategic planning, faculty development, investment in infrastructure, and the incorporation of pedagogically sound design principles will be necessary to ensure equitable, effective, and sustainable implementation.

5. Future Opportunities and Directions

5.1 AI-Powered Precision Education in Burn Anesthesia

The proposed future opportunities were derived from three main sources: gaps identified in the existing literature, expert perspectives reported in narrative reviews and commentary papers, and emerging technological trends in medical education that have not yet been extensively studied. This integrative approach ensured that the proposed directions reflect both evidence-based insights and forward-looking innovations, as also suggested by the reviewers. Artificial intelligence will transform how anesthesiologists train for burn care. Adaptive learning platforms will automatically adjust content difficulty based on individual performance metrics, particularly for complex topics like burn shock resuscitation and inhalation injury management. Virtual patient avatars utilizing generative AI will simulate dynamic burn cases with evolving hemodynamics, enabling trainees to practice time-sensitive decision-making. AI-driven debriefing systems will analyze performance in simulated scenarios to identify recurring knowledge gaps and automatically generate personalized remediation plans tailored to each individual.

5.2 Immersive Procedural Training for Burn-Specific Challenges

Advanced simulation technologies will address the unique needs of burn anesthesia. Haptic-enhanced VR systems will recreate the tactile feedback of difficult intubations through edematous airways. Augmented reality overlays will provide real-time visual guidance during complex procedures, such as central line placement in burned tissue. Metaverse platforms will enable multidisciplinary team training for mass casualty burn scenarios, synchronizing anesthesiologists, surgeons, and nurses in virtual emergency simulations.

5.3 Global Accessibility Solutions for Burn Anesthesia Training

Innovative approaches will bridge resource disparities in burn care education. Low-bandwidth tele-mentoring systems will deliver critical updates via mobile platforms to practitioners in remote areas. Affordable 3D-printed burn simulators with integrated sensors will make hands-on training accessible worldwide. Automated translation tools will help overcome language barriers in international burn care education, ensuring that vital knowledge reaches healthcare providers who do not speak English.

5.4 Enhanced Competency Assessment Frameworks

Next-generation evaluation methods will validate burn anesthesia proficiency. Block chain-secured micro-credentials will document mastery of specific competencies, such as pediatric burn analgesia. Extended reality-based objective structured clinical exams will assess performance through standardized virtual burn cases.

Longitudinal analytics dashboards will track skill progression from simulation performance to actual clinical outcomes in burn centers.

5.5 Clinical Practice Integration Strategies

Seamless connections between education and patient care will be established. Electronic health record-embedded learning tools will provide just-in-time guidance during burn procedures. Secure teleproctoring systems will enable remote expert supervision of complex cases in underserved regions.

Federated learning networks will aggregate de-identified global burn anesthesia data to improve training algorithms while maintaining patient privacy continuously.

5.6 Critical Research Priorities

Key knowledge gaps must be addressed through

targeted investigation. Randomized controlled trials will compare skill acquisition between virtual and traditional training methods. Cognitive load studies will optimize e-learning interfaces for high-stress burn scenarios. Global needs assessments will identify disparities in access to burn anesthesia education, particularly in low-resource settings.

5.7 Implementation Roadmap for Global Adoption

A coordinated international effort will drive widespread adoption. Professional societies must standardize core burn anesthesia competencies for digital curricula. Public-private partnerships should support the development of immersive technology for training programs worldwide. Open-access repositories will share validated virtual burn scenarios across institutions. Continuous outcome monitoring will ensure educational innovations translate to improved patient survival and recovery.

6. Conclusion

The integration of e-learning into anesthesiology education, particularly in burn care, represents a transformative step toward overcoming the limitations of traditional training models. Current applications—including interactive modules, blended formats, and high-fidelity simulations—have demonstrated effectiveness in strengthening knowledge, procedural skills, and crisis management. Emerging technologies, such as VR, artificial intelligence–driven adaptive learning, and gamification, further expand the potential of these platforms by enhancing personalization and scalability. Nonetheless, challenges remain, particularly in terms of infrastructure, faculty preparedness, and integrating hands-on clinical training.

To ensure sustainable impact, future strategies should focus on standardizing curricula to align with accreditation benchmarks, investing in faculty development for digital pedagogy, combining online learning with simulation and clinical apprenticeship in hybrid models, and prioritizing global accessibility through low-bandwidth solutions and equitable partnerships. Equally important is the need for rigorous outcome-based research to evaluate the influence of e-learning on both clinical performance and patient outcomes. With strategic implementation and cross-disciplinary collaboration, e-learning can democratize expertise, foster lifelong learning, and ultimately improve the quality of anesthetic care for burn patients worldwide.

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Authors' contributions

M M: Supervised the project. S R: Conceptualized the review, drafted the manuscript, and coordinated revisions. F M: Contributed to the design and structure of the review, critically reviewed the content, and interpreted data from the literature. Sh SM and J A: Literature search, collected data, and drafted the manuscript. M N, Z Gh and P MM: Wrote or critically revised the manuscript for important intellectual content. All authors discussed the results and contributed to the writing of the final version. All authors have read and approved the final version of the manuscript for publication.

Conflict of interest

No potential conflict of interest was reported by the authors.

Ethical declarations

Not applicable.

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