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State-of-the-art anesthesia practices: a comprehensive review on optimizing patient safety and recovery

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Abstract

Objective This review explores recent advancements in anesthesia care, focusing on the integration of innovative practices to enhance patient outcomes across the perioperative period.

Methods Following the framework of Whitmore and Knafl, we systematically searched six databases (PubMed, Google Scholar, EMBASE, CINAHL, OVID, and Cochrane Library) for studies published from January 2020 to January 2024, relating to advancements in anesthesia care, best practice implementation, and patient outcomes. After independent screening and data extraction by two reviewers, the review focuses on innovations in anesthetic drugs, monitoring technologies, anesthesia techniques, and evidence-based practices in anesthesia and clinical guidelines.

Results Of the 25,984 studies retrieved, 26 met inclusion criteria. Recent developments in anesthetic drugs have improved safety and efficacy, reducing complications. Advanced monitoring devices, such as multiparameter and brain function monitors, have enhanced patient safety through real-time assessments. Innovations in regional anesthesia and ultrasound-guided nerve blocks have led to better pain management, reduced recovery time, and minimized morbidity. Additionally, evidence-based practices like comprehensive preoperative assessment, patient education, and multidisciplinary teamwork significantly improved patient outcomes.

Conclusion Integrating the latest innovations and best practices in anesthesia care is essential for optimizing patient outcomes. Ongoing research and adoption of advanced technologies are crucial to addressing current challenges and enhancing anesthesia quality. This review emphasizes the importance of a holistic approach from preoperative preparation to postoperative recovery to achieve optimal patient outcomes.

Keywords Anesthesia care, Patient outcomes, Best practices, Anesthesia drugs, Clinical guidelines

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Introduction

Anesthesia care, a key component of modern medicine, has undergone remarkable development and made significant progress over the past century. It has evolved from basic monitoring and pain relief to a specialized care system involving multidisciplinary collaboration. Despite these achievements, anesthesia care still faces a series of challenges. One of the most significant problems is the high incidence of intraoperative complications, which can be caused by a variety of factors, including the complexity of the procedure, patient comorbidities, and the management of the anesthesia itself [1–3]. These complications range from minor to severe, life-threatening events, making intraoperative management a primary focus for anesthesia professionals [4, 5]. Patient safety concerns span all perioperative stages, including preoperative preparation, intraoperative management, and postoperative recovery. Postoperative recovery issues such as inadequate pain management, infection risk, and delayed rehabilitation, continue to plague healthcare workers and patients, affecting patient prognosis and increasing the burden on healthcare resources [6–8].

Recent innovations in anesthetic drugs, monitoring technologies, and anesthesia techniques have shown promise in mitigating these challenges. This paper aims to explore these advancements, highlighting their significance in enhancing patient safety, improving recovery outcomes, and integrating best practices to optimize clinical results. By adopting innovative technologies and methodologies, anesthesia professionals can continue advancing perioperative care and achieving better outcomes for patients.

Methods

Review design

This literature review was conducted following the PRISMA guidelines [9]and utilizing the integrative review method as outlined by Whittemore and Knafl [10]. By employing this integrative approach, we were able to synthesize qualitatively the selected studies. This integrative review enabled the observation of advancements in anesthesia care, implementation of best practices, and the impact on patient outcomes. The scope of this review specifically focuses on general anesthesia, addressing its advancements and clinical applications. The findings could provide a theoretical basis for applying these advancements in clinical practice and guiding future research in anesthesia care.

Search strategy

A comprehensive literature search was performed through six databases: PubMed, Google Scholar, EMBASE, CINAHL, OVID, and Cochrane Library. The search covered publications from January 2020 to January 2024. We developed a detailed search strategy using both subject-specific terms and free-text keywords related to advancements in anesthesia care. The key terms included "advancements in anesthesia care," "best practices in anesthesia," "patient outcomes in anesthesia," "innovations in anesthetic drugs," "monitoring technologies in anesthesia," and "anesthesia techniques," along with their relevant synonyms. Additionally, references cited in the selected articles were manually reviewed to ensure comprehensive coverage.

The inclusion criteria included: (1) The study was published between January 2020 and January 2024. (2) Research needs to be published in English. (3) Includes research on anesthesia drug innovations, monitoring techniques, anesthesia technology, and evidence-based practice and clinical guidelines. (4) studies are required to provide empirical data on anesthesia care to improve safety, increase efficacy, and reduce complications.

The exclusion criteria included: (1) Significant flaws in study design or methodology resulting in low reliability of results. (2) commentaries, editorials or conference abstracts, etc.

Literature selection and extraction

The literature selection and extraction process was conducted following the predefined retrieval strategies and inclusion and exclusion criteria. Two researchers, L. X. and H. C., independently performed the screening and data extraction. If any discrepancies arose during the literature screening process, a third researcher was consulted to resolve the differences and reach a consensus. The selection and extraction process involved the following steps: (1) Initial Screening: Titles and abstracts of the retrieved studies were reviewed to exclude irrelevant and duplicate articles. (2) Full-text Review: The full texts of the preliminarily included studies were thoroughly read to determine their eligibility based on the inclusion and exclusion criteria. (3) Data Extraction: Using a standardized data extraction form, the following information was collected from each included study: First author, Publication year, Study design, Sample size, Anesthesia techniques, Age and gender of participants, Details of intervention and control groups, Outcome measures and tools and Main findings.

Quality assessments

Quality assessments of the included studies were performed using the Mixed Method Appraisal Tool (MMAT) [11]. The MMAT was used to assess the methodological rigor of the included studies across multiple dimensions, such as the study design, sample size, data collection methods, and data analysis procedures. A thorough evaluation was conducted to identify the strengths and weaknesses of each study, including potential sources

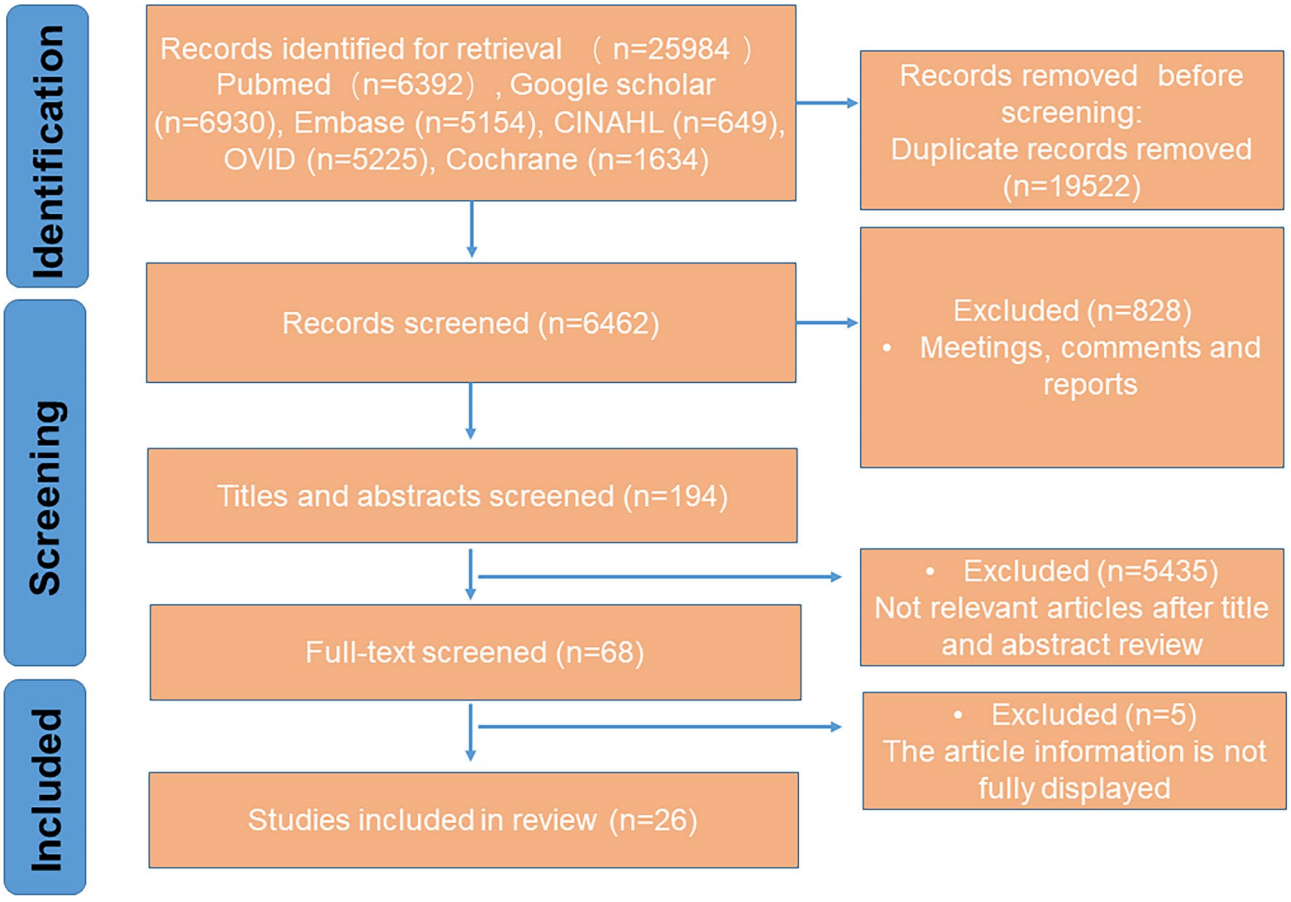

Fig. 1 Flow diagram of literature search

of bias and the reliability of their results. In particular, we assessed how methodological rigor could influence the findings of the review, including the reliability of reported outcomes. For example, studies with randomized controlled trials (RCTs) were considered to have higher methodological rigor, while those with smaller sample sizes or potential biases (such as funding sources or lack of blinding) were considered with more caution. This evaluation of study quality helped ensure that the synthesis of findings was based on the most reliable evidence, with clear acknowledgment of the limitations of studies with lower quality.

Results

Search results

A total of 25,984 articles were retrieved, of which 19,522 were duplicated, and 5629 had read titles and abstracts, after reviewing the abstracts, 194 articles were retained, and 121 were excluded after reading the full text, of which 5 were excluded due to inaccessibility of the original text. The remaining 26 studies were included in the review, with a focus on assessing postoperative recovery, including long-term outcomes such as complications, chronic pain, and rehabilitation. Of the included studies, 10 were randomized controlled trials (RCTs), which represent the highest level of evidence in clinical research, while the remaining 16 were observational studies or case series that may carry risks of bias due to small sample sizes or funding influences. The screening and exclusion process is shown in Fig. 1.

Recent advances in anesthesia care

Drug innovation in anesthesia

Recent advancements in anesthetic drugs have aimed at enhancing patient safety and optimizing postoperative recovery. One of the widely discussed drugs is liposomal bupivacaine, which uses a sustained-release mechanism to extend analgesic effects up to 72 h. Despite its promise, the included studies showed variability in methodological rigor. For example, several trials lacked adequate blinding or had small sample sizes, raising concerns about potential bias. This new formulation has shown excellent performance in postoperative pain management, particularly for surgeries requiring long-lasting pain relief [12–14]. However, it is important to note that while liposomal bupivacaine has gained significant attention in recent years, its first formulations appeared as early as the 1990s to 2000s for animal use, with one of the first large-scale

clinical studies conducted in 2012 for total knee arthroplasty patients [15]. Therefore, despite the recent surge in its clinical application, liposomal bupivacaine is not a novel drug from a historical perspective.

Some studies indicated that liposomal bupivacaine may not be superior to conventional anesthesia methods in certain surgeries, and thus its clinical application still requires further validation [16–18]. For instance, a multicenter trial demonstrated inconsistent outcomes across study centers, suggesting variability in the generalizability of its efficacy. Moreover, several studies were funded by pharmaceutical companies, which may introduce potential conflicts of interest. In addition to standard efficacy measures, several trials also evaluated patient-reported outcomes, such as postoperative pain perception and satisfaction with recovery. These studies reported improved quality of life and reduced reliance on opioid medications, linking liposomal bupivacaine use with enhanced long-term recovery and higher patient satisfaction. Compared to traditional local anesthetics, liposomal bupivacaine offers the significant advantage of sustained analgesia, which can reduce the frequency of drug administration and improve patient compliance. This extended duration of action minimizes the need for repeated interventions, thereby reducing risks associated with repeated dosing, such as infection or local irritation at the injection site. Moreover, its potential to reduce opioid consumption addresses a critical need in pain management, especially in light of the opioid crisis. However, its cost remains a major consideration. Studies suggest that liposomal bupivacaine is significantly more expensive than traditional alternatives such as plain bupivacaine, which may limit its accessibility in resource-constrained settings. A cost-effectiveness analysis comparing the upfront costs with the potential reduction in opioid use and hospital stay would be crucial for healthcare policymakers to evaluate its overall value. While patient outcomes such as pain relief and recovery times have been extensively studied, understanding patient preferences is equally critical for evaluating the practical impact of liposomal bupivacaine. For instance, some patients may prioritize reducing opioid consumption due to concerns about addiction or side effects, making liposomal bupivacaine a particularly appealing choice. Additionally, patients' concerns about the cost of advanced drugs may influence their willingness to adopt such innovations, highlighting the need for transparent discussions about the benefits and affordability of these therapies in clinical practice.

To further evaluate its efficacy, several clinical trials have been conducted. For instance, in a randomized controlled trial involving 100 patients undergoing knee replacement surgery [19], the group treated with liposomal bupivacaine reported significantly lower hospital length of stay compared to the control group receiving ropivacaine (36.3 vs. 49.7 h, $P<0.01$). Additionally, patients who received liposomal bupivacaine block used significantly less narcotic medication during their hospital stay compared with those who received the control medication block (40.9 vs. 47.3 MME/d, $P=0.04$), indicating its potential to reduce opioid-related adverse effects and promote early recovery. This reduction in opioid usage is particularly important in preventing opioid-related adverse effects such as nausea, constipation, and respiratory depression, which are common concerns in postoperative care. Some of these studies also evaluated long-term recovery outcomes, such as reductions in chronic pain and the need for prolonged rehabilitation, highlighting its broader implications for patient recovery. Nevertheless, the higher cost of liposomal bupivacaine may overshadow these clinical benefits in certain healthcare systems, particularly when considering its comparable efficacy to traditional formulations in some surgical scenarios. However, the benefits of liposomal bupivacaine were less pronounced in certain cases. For example, in a trial conducted in the context of interscalene brachial plexus block for shoulder surgeries, a comparison between liposomal bupivacaine and bupivacaine with dexamethasone showed no significant difference in pain scores, duration of analgesia, motor and sensory resolution, or opioid consumption between the groups. These findings suggest that while liposomal bupivacaine is effective, its advantages may not be significant compared to conventional formulations with adjuncts in some surgical scenarios [17]. Integrating qualitative patient feedback in future studies could further elucidate how such drugs align with patient priorities, such as minimizing discomfort, avoiding opioids, and achieving quicker recovery, thereby strengthening the case for their use in patient-centered care models.

Moreover, a multicenter study focusing on abdominal surgeries demonstrated mixed results. While patients receiving liposomal bupivacaine had slightly better pain control in the first 72 h, the difference was not statistically significant in all participating centers, indicating that the efficacy might vary depending on the surgical context and patient-specific factors [20, 21]. Given its high cost, a more comprehensive cost-benefit analysis is necessary to determine its feasibility for widespread clinical use, especially in settings with budgetary constraints. Patient-reported outcomes in this context revealed variability in satisfaction, influenced by differences in individual pain thresholds and recovery expectations. And They also examined postoperative rehabilitation outcomes and noted that patient-specific factors could influence the duration of recovery and the recurrence of postoperative complications. This variability highlights the importance

of considering the type of surgery and individual patient characteristics when choosing analgesic strategies.

Another drug is Hyperbaric Prilocaine, which has received attention for its rapid onset of action and lower incidence of transient neurologic symptoms (TNS) [22]. The initial studies of Hyperbaric Prilocaine date back to 2010 [23]. Although recent research has focused on its clinical applications, the drug has been in use for many years. Studies have shown that Hyperbaric Prilocaine in spinal anesthesia has more predictable motor and sensory blockade with shorter recovery time for outpatient surgery patients [22–26].

For instance, a prospective randomized controlled trial compared hyperbaric prilocaine with hyperbaric bupivacaine for elective caesarean Sect. [27]. The results indicated that patients receiving hyperbaric prilocaine experienced a significantly shorter duration of motor block (median [IQR]: 110 [104 to 150] minutes) compared to those receiving bupivacaine (175 [135 to 189] minutes, $P = 0.001$). Furthermore, patients in the prilocaine group were able to ambulate without assistance significantly earlier (median [IQR]: 204.5 [177 to 246.5] minutes versus 314 [209.25 to 400] minutes, $P = 0.007$). Additionally, maternal hypotension was more frequently observed in the bupivacaine group ($P = 0.033$). Importantly, none of the patients required supplementary epidural analgesia. Compared to traditional anesthetic agents like bupivacaine, hyperbaric prilocaine demonstrates significant advantages in specific clinical scenarios. Its shorter motor block duration allows for faster postoperative mobility, which is particularly beneficial for outpatient procedures or surgeries requiring early ambulation, such as caesarean sections or lower extremity surgeries. Furthermore, the reduced incidence of maternal hypotension highlights its safety profile, addressing a common concern in spinal anesthesia. This characteristic is especially valuable in obstetric anesthesia, where hemodynamic stability is critical for both maternal and fetal outcomes. These results suggest that hyperbaric prilocaine may offer advantages in terms of faster recovery and reduced side effects when compared to other commonly used anesthetic agents. However, it is important to note that while hyperbaric prilocaine has a favorable profile in certain contexts, its use might be limited by its shorter duration of sensory blockade, which may not be suitable for longer surgeries. This highlights the need to tailor anesthetic choices based on the type and duration of surgery as well as patient-specific factors, ensuring that its benefits are maximized in appropriate clinical scenarios. These findings position hyperbaric prilocaine as a valuable option for surgeries where quick recovery is a priority, particularly when early mobility and minimized hospital stay are key objectives. Future studies should explore its cost-effectiveness compared to other anesthetic agents, especially in resource-limited settings where faster turnover of surgical patients could have significant operational and economic benefits.

Sugammadex is a selective neuromuscular blocker reversal agent that was approved for clinical use in the European Union in 2008 and in the United States in 2015, significantly enhancing anesthesia safety [28, 29]. Sugammadex was able to rapidly reverse the effects of non-depolarizing neuromuscular blockers like rocuronium and vecuronium, greatly reducing the incidence of postoperative respiratory complications [30, 31]. Compared to traditional reversal agents like neostigmine/atropine, recent studies have shown that it offers more advantages, with initial strong evidence dating back to 2010 [32].

In a randomized clinical trial involving patients undergoing general anesthesia with non-depolarizing muscle relaxants, those treated with sugammadex experienced faster and more complete recovery of neuromuscular function compared to those receiving traditional reversal agents like neostigmine. Specifically, sugammadex shortened the median recovery time from neuromuscular blockade to less than five minutes, compared to over 15 min in the neostigmine group. Moreover, patients in the sugammadex group had a notably lower incidence of respiratory issues post-surgery, which is particularly critical for patients with pre-existing respiratory dysfunction. These benefits translate into improved patient outcomes, especially in reducing the risk of pulmonary complications and enhancing recovery quality in high-risk patient populations [28, 33]. These findings underscore the value of sugammadex as a critical advancement in anesthesia practice, particularly for patients vulnerable to respiratory complications, highlighting its role in improving perioperative safety and patient comfort.

Advancements in anesthesia techniques

In recent years, innovations in anesthesia techniques have significantly improved the safety and efficacy of anesthesia care. These advancements include Target-Controlled Infusion (TCI), Ultrasound-Guided Regional Anesthesia (UGRA), and Closed-Loop Anesthesia Systems, which are still under development and not yet widely implemented in clinical practice [34, 35].

Target-Controlled Infusion (TCI) is an advanced intravenous anesthesia delivery technique in which a computer-controlled infusion pump precisely calculates and maintains a target concentration of anesthetic drug in the plasma based on parameters such as the patient's age, weight, and health status [36]. This technique allows for a smoother induction and maintenance of anesthesia and helps to reduce the risk of intraoperative awakening and anesthetic drug overdose [37, 38]. TCI studies have also explored patient-reported outcomes, finding improvements in comfort during recovery and reduced cognitive

impairments post-surgery, which positively influenced overall patient satisfaction. Additionally, new pharmacokinetic models for TCI are under evaluation, but may not have been identified in the literature search for this manuscript. Certain studies also assessed the impact of TCI on long-term recovery, highlighting its role in minimizing residual anesthetic effects and reducing the risk of postoperative cognitive dysfunction, particularly in elderly patients. However, the cost of implementing TCI, particularly for acquiring advanced infusion pumps and training staff, may limit its widespread adoption in resource-limited settings. A detailed cost-benefit analysis would be beneficial to assess its feasibility in these environments.

Ultrasound-Guided Regional Anesthesia (UGRA) utilizes real-time ultrasound imaging to help anesthesiologists accurately locate nerves and surrounding tissues, thereby improving anesthesia efficacy and reducing complications. The application of UGRA is extensive, including nerve block and intralesional anesthesia, and has shown significant advantages especially in complex anatomical structures and high-risk patients [39, 40]. Studies have shown that the UGRA technique not only increases the success rate of anesthesia, but also significantly reduces the incidence of anesthesia-related complications [34, 40, 41]. Moreover, UGRA has demonstrated benefits in accelerating postoperative recovery by reducing the need for systemic analgesics, which can contribute to improved rehabilitation outcomes and reduced risk of chronic pain. Despite these clinical advantages, UGRA's cost-effectiveness remains a critical concern, especially in resource-constrained healthcare systems. The high cost of ultrasound equipment and the need for specialized training could pose barriers to its widespread implementation. Further studies comparing UGRA's upfront costs with its potential to reduce complications, enhance recovery, and decrease long-term healthcare expenses would provide valuable insights for healthcare administrators and policymakers.

The closed-loop anesthesia system combines modern control theory and artificial intelligence technology to automatically adjust the rate of anesthetic drug administration and maintain the patient's physiological parameters within a safe range [42, 43]. This system automatically adjusts the anesthetic dose by monitoring the patient's vital signs in real time, such as blood pressure, heart rate, and brain waves, to ensure the depth and stability of the patient's anesthesia throughout the surgical process [43, 44]. The application of the closed-loop anesthesia system not only improves the efficiency of anesthesia management, but also reduces the workload of anesthesiologists and significantly improves patient safety and comfort. Studies have begun exploring its implications for long-term recovery, including its potential to decrease the incidence of postoperative complications, enhance rehabilitation, and support faster return to normal activity levels. However, similar to TCI and UGRA, the high initial costs of acquiring and maintaining such systems, along with the complexity of integrating them into existing workflows, could challenge their adoption in under-resourced settings. Evaluating their cost-effectiveness in terms of reduced complications and improved efficiency will be crucial for determining their broader applicability.

Advancements in anesthesia methods

In recent years, improvements in anesthesia methods in clinical practice have significantly enhanced patient safety and comfort. These advancements are primarily reflected in the application of multimodal analgesia, Enhanced Recovery After Surgery (ERAS) protocols, and personalized anesthesia plans.

(1) Multimodal analgesia: Multimodal analgesia is an approach to control postoperative pain by combining analgesic medications and techniques with different mechanisms. This approach aims to reduce reliance on a single medication (e.g., opioids), thereby reducing its side effects. Multimodal analgesia includes the use of NSAIDs, local anesthetics, NMDA receptor antagonists, and nerve blocks. Studies [45–47] have shown that multimodal analgesia significantly improves postoperative pain management, reduces the incidence of postoperative complications, and accelerates patient recovery. However, most of these studies were conducted in single-center settings, potentially limiting their external validity. Additionally, few studies systematically assessed long-term adverse events, such as delayed wound healing or persistent pain. Beyond these objective clinical outcomes, patient preferences also play a crucial role in the effective implementation of multimodal analgesia. For instance, patients who are particularly concerned about opioid-related side effects or potential dependency may be more inclined to accept alternative analgesic regimens that emphasize non-opioid modalities. Likewise, individuals who prioritize a swift return to daily activities might favor a combination of nerve blocks and local anesthetics to reduce sedation and facilitate earlier mobility. Incorporating patient feedback into analgesic planning not only aligns treatment with individual values but may also improve adherence to postoperative pain management protocols, ultimately enhancing patient satisfaction and recovery experiences. (2) ERAS: ERAS is a multidisciplinary collaborative approach designed to accelerate postoperative recovery by optimizing preoperative, intraoperative, and postoperative care measures. ERAS includes measures such as preoperative education and preparation, minimizing intraoperative fluid overload, using multimodal analgesia, and encouraging early mobilization. Studies [48–51] have shown that the ERAS

pathway can significantly shorten hospitalization time, reduce postoperative complications, and improve patient satisfaction. Long-term recovery assessments in ERAS studies have demonstrated a notable reduction in chronic postoperative issues and improved patient quality of life during rehabilitation. Despite these benefits, the included studies varied widely in their implementation protocols, which may contribute to inconsistent findings in recovery metrics. (3) Personalized anesthesia plans: Personalized anesthesia plans are tailored to the individual characteristics of patients (e.g., age, weight, medical history, and type of surgery). This approach involves selecting the most appropriate anesthetic drugs and techniques by considering patient-specific differences, thereby optimizing anesthesia outcomes and minimizing side effects. Personalized anesthesia plans enhance patient safety and comfort, reduce intraoperative and postoperative complications, and significantly improve patient prognosis [52]. Studies have emphasized the importance of personalized plans in managing long-term complications, such as persistent pain or delayed rehabilitation, thus ensuring better long-term recovery outcomes. Besides, despite its potential, personalized plans require significant time and resource investment, as well as multidisciplinary collaboration, which may limit their feasibility in resource-limited settings. Identifying cost-effective strategies for implementing personalized care without compromising quality will be critical for its widespread adoption.

Integrating best practices

Evidence-Based Medicine (EBM): The application of Evidence-Based Medicine (EBM) in anesthesia care involves integrating high-quality research evidence, clinical experience, and patient values to develop and implement best practices. This process includes systematic retrieval, evaluation, and integration of evidence to provide a scientific basis and optimize patient outcomes. The following are specific applications of EBM in anesthesia care:

Multimodal analgesia

Multimodal analgesia manages postoperative pain by combining medications with different mechanisms of action, thereby reducing the side effects and dependence of a single drug, such as opioids [46, 53, 54]. Patient-reported outcome measures, such as reduced pain scores, improved quality of life during recovery, and high satisfaction levels, have consistently supported the efficacy of multimodal analgesia. Numerous studies have shown that multimodal analgesia significantly improves the effectiveness of postoperative pain management, reduces postoperative complications, and promotes rapid patient recovery [54, 55]. In addition to these short-term benefits, studies have explored its effectiveness in reducing the prevalence of chronic postoperative pain, demonstrating its potential to improve long-term recovery outcomes. For example, in a study involving 153 patients undergoing percutaneous nephrolithotomy (PCNL), patients in the multimodal analgesia group had better real-time analgesia than the single analgesia group at the T10-15 time point, and the duration of postanesthesia care unit (PACU) hospitalization in the multimodal paroxysmal analgesia group was significantly shorter than that in the single analgesia group (mean [SD]: 54.35 [16.61] vs. 47.39 [13.15], $P = 0.04$) [46]. Additionally, in a study conducted by Joann M. Butkus et al. on postoperative pain treatment in otologic surgery, the multimodal analgesia cohort consumed significantly fewer opioids on average than the opioid monotherapy cohort (11.9 ± 15.9 MME vs. 22.8 ± 28.0 MME, respectively) [56].

ERAS

The ERAS pathway is a comprehensive approach to accelerate a patient's postoperative recovery by optimizing preoperative, intraoperative, and postoperative care measures. ERAS emphasizes multidisciplinary collaboration, including anesthesiologists, surgeons, nurses, and nutritionists, to ensure optimal care throughout the perioperative period. For instance, the consensus statement from the Society for Obstetric Anesthesia and Perinatology on enhanced recovery after cesarean delivery highlights the importance of early activity and nutritional support for accelerating recovery [57]. However, while the benefits of ERAS in terms of reduced complications and enhanced recovery are clear, the cost-effectiveness of implementing ERAS protocols in resource-limited settings requires further evaluation. For example, the financial burden of staff training, patient education, and additional perioperative resources may outweigh the benefits in systems with constrained budgets. Identifying scalable components of ERAS protocols that provide the greatest return on investment will be essential for broader implementation. Specific recommendations include: encouraging patients to ambulate within 6 h post-surgery to promote circulation and prevent thrombosis, providing a high-protein, high-vitamin diet to support tissue repair and immune function, using spinal or epidural anesthesia during surgery to reduce the side effects and recovery time associated with general anesthesia, and offering detailed preoperative education and psychological preparation to alleviate preoperative anxiety and to improve adherence to postoperative recovery measures. Long-term recovery assessments within the ERAS pathway have demonstrated reduced risks of chronic postoperative complications, such as prolonged fatigue or infections, and have been associated with better rehabilitation outcomes and improved overall quality of life. For example, a clinical study demonstrated that applying these recommendations resulted in higher

thermal comfort scores 120 min after early oral intake of carbohydrates post-cesarean section compared to traditional care ($P = 0.02$), and higher maternal satisfaction visual analog scores ($P < 0.001$) [58]. Similarly, Angelica Vargas et al. indicated that anesthesia-related complications in pediatric patients can be significantly reduced by detailed preoperative evaluation, intraoperative use of ultrasound-guided techniques, and close postoperative monitoring [59]. Furthermore, patient preferences regarding the pace of recovery and readiness for ambulation can heavily influence adherence to ERAS protocols. Some patients may be hesitant to begin early mobilization due to fears of postoperative pain or complications, underscoring the need for shared decision-making. Incorporating patient education sessions that address these concerns—explaining the benefits, safety measures, and expected outcomes—can increase their willingness to participate. Similarly, individual dietary habits or cultural beliefs around postoperative meal timing may affect acceptance of early nutritional protocols. By engaging patients in the decision-making process and respecting personal or cultural preferences, ERAS interventions can be tailored more effectively, leading to higher satisfaction rates and potentially improving overall recovery outcomes.

Personalized anesthesia plans

Personalized anesthesia plans are tailored anesthesia care strategies based on the specific characteristics of the patient, such as age, gender, weight, medical history, and type of surgery. This approach optimizes the effectiveness of anesthesia and reduces side effects by taking into account individual patient differences and selecting the most appropriate anesthetic medications and techniques. In addition to improving immediate outcomes, personalized anesthesia plans have been linked to enhanced long-term recovery by addressing patient-specific risks of chronic pain, prolonged rehabilitation, and complications from comorbidities. For example, the ICAROS consensus recommendations suggest detailed strategies for personalized anesthesia care for patients undergoing initial hip and knee arthroplasty [60]. Preoperatively, a comprehensive patient assessment, including cardiopulmonary function tests, allergy history, and medication history, is recommended to identify potential risks. Intraoperatively, precise anesthesia monitoring equipment, such as an electroencephalogram dual-frequency index (BIS) monitor, is used to continuously monitor the depth of anesthesia [61]. This ensures that the patient is in an optimal state of anesthesia and to reduce the risk of intraoperative awareness and anesthetic overdose. Postoperatively, a personalized pain management plan is developed, combining local anesthetics, NSAIDs, and opioids to ensure patient comfort and promote rapid recovery [60, 62]. Beyond these clinical considerations, patient preferences are integral to the success of personalized anesthesia plans. Some patients may have concerns about opioid use due to prior personal or family history of substance misuse, while others may prioritize the speed of postoperative recovery to resume work or caregiving responsibilities. By involving patients in shared decision-making—discussing the potential benefits and drawbacks of various anesthetic modalities—clinicians can better align treatment with individual values and lifestyles. Incorporating qualitative data, such as patient interviews or surveys, can further illuminate these preferences, allowing for more nuanced tailoring of anesthesia plans. This patient-centered approach not only enhances adherence and satisfaction but may also improve long-term outcomes by reducing anxiety and fostering greater trust in the care team.

Safety and complication management

Safety and complication management in anesthesia care are crucial for ensuring patient safety and optimizing postoperative recovery. Evidence-based medicine provides a scientific basis for preventing and managing anesthesia-related complications through high-quality research evidence. For example, the Review and Clinical Guidelines on Neurological Complications of Regional Anesthesia recommends improving the accuracy of anesthesia needle insertion and reducing the risk of nerve injury through a detailed preoperative understanding of the patient's medical history and health status, the use of neurostimulators or ultrasound-guided techniques during the operation, and routinely assess the patient's neurological function postoperatively to promptly detect and address any abnormalities [63]. Studies have also highlighted the importance of managing long-term complications, including the development of chronic pain and neurological impairments, to improve the overall recovery trajectory. For instance, regular follow-ups and patient monitoring have been shown to reduce the incidence of persistent nerve injuries, facilitating better rehabilitation outcomes.

Clinical guidelines

Clinical guidelines are standard documents that provide specific operational recommendations based on evidence-based medicine. These guidelines play a key role in anesthesia care by standardizing care processes and operational protocols, thereby enhancing patient safety and the quality of care. The following are important clinical guidelines in anesthesia care and their specific applications:

Comprehensive anesthesia practice guidelines

The Anesthesia Practice Guidelines (2023 Revision) [64] provide detailed standards for anesthesia practice, covering all aspects of anesthesia from preoperative assessment to intraoperative management to postoperative care. These guidelines have increasingly incorporated patient-reported outcomes as part of routine evaluations, emphasizing their role in identifying gaps in care and ensuring personalized, patient-centered practices.

(1) Preoperative assessment: The guidelines recommend a comprehensive patient evaluation before surgery, including history taking, physical examination, and necessary laboratory tests. For patients with a history of cardiac disease, an electrocardiogram and cardiac function assessment are advised to develop a safe anesthesia plan [63, 65]. A study conducted by Yuki Ushimaru et al. demonstrated that gastric cancer patients who received Comprehensive Preoperative Assessment and Support (CPAS) had a significantly shorter average hospital stay (10 days vs. 15 days, $P < 0.001$) and no in-hospital deaths [66]. (2) Intraoperative management: The guidelines emphasize continuous monitoring of vital signs during surgery, including heart rate, blood pressure, and oxygen saturation, using multiparameter monitors to promptly detect and address any abnormalities [63]. A recent study found that processed EEG-guided general anesthesia management, including PSI and DSA monitoring, significantly reduces the risk of postoperative delirium in patients undergoing carotid endarterectomy (CEA). Patients exhibiting hemodynamic fluctuations or undergoing surgeries that may disrupt cerebral perfusion could particularly benefit from monitoring multiple EEG parameters during the surgical procedure [67]. (3) Postoperative care: For postoperative care, the guidelines recommend the development of a personalized pain management plan that combines the use of analgesic pumps, NSAIDs, and local anesthetics to effectively control postoperative pain, as well as close observation of the patient's recovery, and timely management of any complications [63]. Studies have shown that personalized pain management plans can significantly reduce postoperative pain scores and promote rapid patient recovery [63, 68, 69].

Anesthesia guidelines for specific populations

Pediatric anesthesia guidelines The Safety Guidelines for Pediatric Regional Anesthesia provide safety recommendations for pediatric regional anesthesia, with a particular focus on preventing and managing complications.

Preoperative assessment: Conduct a thorough health assessment of children before surgery, including medical history, allergy history, and current medication usage. Special attention should be given to selecting and adjusting anesthesia plans for children with bleeding disorders or neurological diseases [63]. Studies have shown that detailed preoperative evaluation can significantly reduce the incidence of anesthesia-related complications in pediatric patients [70, 71].

Intraoperative techniques: Ultrasound-guided techniques are recommended to improve the accuracy of anesthesia needle insertion and reduce the risk of nerve and vascular injury [63].

Postoperative management: Closely monitor the vital signs and anesthetic effects in children postoperatively, and promptly address any adverse reactions. Regularly assess the child's sensory and motor functions to ensure there are no signs of nerve damage, and provide effective pain management measures to ensure the child's comfort and rapid recovery [63]. Follow-up studies indicate that proactive postoperative monitoring reduces the likelihood of long-term complications, such as chronic pain or nerve dysfunction, and facilitates smoother rehabilitation for pediatric patients.

Obstetric anesthesia guidelines The Consensus Statement on Enhanced Recovery After Cesarean Delivery was jointly developed by the Society for Obstetric Anesthesia and Perinatology, proposing comprehensive strategies for accelerated recovery.

Preoperative education and preparation: Emphasizes detailed preoperative education and psychological preparation to reduce preoperative anxiety and improve patient adherence to postoperative recovery measures [57]. For example, a study showed that preoperative education significantly reduced patients' postoperative anxiety levels and markedly improved the speed of postoperative recovery [72].

Intraoperative anesthesia management: Regional anesthesia techniques such as epidural or spinal anesthesia are recommended to reduce the risk of general anesthesia and postoperative recovery time [73].

Postoperative recovery measures: Encourage patients to mobilize early to promote blood circulation and prevent thrombosis, while providing a high-protein, high-vitamin diet to support tissue repair and immune function. Long-term recovery assessments in obstetric patients have shown that these enhanced recovery measures reduce the incidence of chronic pelvic pain, aid in hormonal and physical recovery, and improve maternal health outcomes over time. For example, initiating mild activities such as sitting up at the bedside and walking within 6 h postoperatively, along with increasing protein- and vitamin-rich foods in the diet, helps promote wound healing and physical recovery [57].

Guidelines for specific anesthesia techniques The guideline review potential neurological complications that may arise during regional anesthesia and provide

specific recommendations for preventing and managing these complications [63].

Preventive measures: Conduct a thorough preoperative assessment of the patient's medical history and health status to identify factors that may increase the risk of neurological complications. For patients with a history of neurological disorders, anesthesia and medications should be chosen with particular care.

Technical Procedures: During anesthesia administration, it is recommended to use nerve stimulators or ultrasound-guided techniques to improve the accuracy of needle insertion and reduce the risk of nerve injury. For example, when performing lumbar plexus nerve blocks, using a nerve stimulator can ensure that the needle tip is close to the nerve without directly penetrating it, thereby enhancing the anesthetic effect and reducing complications.

Postoperative monitoring: Routinely assess the patient's neurological function to promptly identify and address any abnormalities. Regularly check the patient's sensory and motor functions within the first 24 h after anesthesia to ensure there are no signs of nerve damage. If any abnormalities were detected, appropriate treatment measures should be taken immediately to minimize the occurrence of long-term complications.

Multidisciplinary collaboration

The importance of multidisciplinary collaboration in anesthesia care is increasingly evident, especially in the management of complex surgeries and high-risk patients, Integrating the expertise and knowledge from various specialties can markedly improve patient outcomes and the quality of care. The following are key aspects of multidisciplinary collaboration in anesthesia care:

Perioperative team collaboration

Perioperative collaboration is a model that integrates anesthesiologists, surgeons, nurses, and other professionals to jointly manage preoperative, intraoperative, and postoperative care of patients. Studies have shown that perioperative collaboration can enhance patient safety and the quality of postoperative recovery. In addition, such collaboration has demonstrated positive impacts on long-term recovery, including fewer chronic complications and enhanced patient satisfaction during rehabilitation. For example, comprehensive preoperative assessment and risk management by a multidisciplinary team, coordinated teamwork during surgery to ensure a smooth procedure, and continuous care and support postoperatively can significantly reduce postoperative complications and improve patient satisfaction [74, 75]. Moreover, involving the patient's perspective is essential for maximizing the benefits of perioperative collaboration. By incorporating patient-reported concerns—such as pain tolerance, medication apprehensions, or personal recovery goals—into team discussions, healthcare providers can better align treatment plans with individual preferences. This open communication fosters a sense of shared decision-making, encouraging patients to be active participants rather than passive recipients of care. As a result, patient adherence to perioperative instructions (e.g., early mobilization and dietary recommendations) may improve, ultimately leading to more successful outcomes and higher patient satisfaction.

Personalized care plans

Personalized care plans are tailored to the specific characteristics of patients, including age, sex, weight, medical history, and type of surgery. Multidisciplinary collaboration plays a key role in developing and implementing personalized care plans. Including patient-reported outcomes, such as satisfaction with anesthesia and recovery experiences, helps ensure that personalized care meets individual needs effectively, addressing both clinical and psychological recovery goals. By integrating expertise from various fields, a multidisciplinary team can create the most appropriate care plan for each patient. For example, for patients with heart disease, anesthesiologists, cardiologists, and nurses collaboratively develop anesthesia and postoperative monitoring plans, significantly improving patient safety and postoperative recovery quality [66, 76]. Studies have shown that for elderly patients with complex medical histories, personalized care plans developed through multidisciplinary teamwork can significantly reduce postoperative complications, including infections, thrombosis, and postoperative cognitive dysfunction, and notably shorten hospital stays [66]. In addition to medical considerations, incorporating patient preferences in the development of personalized care plans can further enhance their efficacy. Some patients might place a higher value on minimizing sedation to return to daily activities quickly, while others may prioritize minimizing pain at all costs, even if it means accepting a longer recovery period. Open dialogue between patients and the care team allows these preferences to be discussed openly, leading to a tailored plan that respects individual goals and concerns. This patient-centered approach not only improves compliance with postoperative instructions but also helps build trust and fosters more positive healthcare experiences.

ERAS

ERAS is a comprehensive approach aimed at accelerating postoperative recovery by optimizing preoperative, intraoperative, and postoperative care measures. ERAS emphasizes multidisciplinary collaboration, including anesthesiologists, surgeons, nurses, and dietitians, to ensure optimal care throughout the perioperative period.

The successful implementation of ERAS relies on a coordinated multidisciplinary team [77, 78]. For example, studies have shown that the ERAS pathway can be effective in reducing hospital stays and postoperative complications with detailed preoperative patient education and psychological preparation, intraoperative use of regional anesthesia techniques, and postoperative encouragement of early mobility and nutritional support [57]. Long-term outcomes in ERAS studies have shown reduced rates of chronic postoperative pain, enhanced patient quality of life, and shorter time to full rehabilitation, further supporting the value of this multidisciplinary approach. In a study of patients undergoing colorectal surgery, it was shown that the number of patients with moderate to severe complications was lower in the ERAS group (25.2% vs. 30.3%; odds ratio [OR], 0.77; 95% CI, 0.63–0.94; $P = 0.01$). And in terms of type of complications, the ERAS group had a reduction in rates of paralytic ileus (OR, 0.74; 95% CI, 0.57–0.95; $P = 0.02$), urinary tract infection (OR, 0.51; 95% CI, 0.26–0.99; $P = 0.04$), and infection of uncertain origin (OR, 0.45; 95% CI, 0.2–0.99; $P = 0.02$) [79]. While ERAS protocols are largely evidence-based, patient preferences can significantly influence the success of these interventions. Some patients may have cultural or personal beliefs about diet and physical activity levels, potentially impacting their willingness to adopt early mobilization or nutritional guidelines. Others may fear discomfort or complications that they believe are associated with accelerated recovery strategies, such as early ambulation. Incorporating patient education sessions that include practical demonstrations, peer support, or testimonials from other patients who have experienced ERAS can help address these concerns. Moreover, allowing patients to express their expectations and anxieties during preoperative consultations can guide clinicians in tailoring ERAS elements—such as stepwise mobilization schedules or modified dietary plans—to align better with individual preferences. In doing so, the care team can foster greater patient engagement and adherence, ultimately enhancing ERAS outcomes and improving overall patient satisfaction.

In summary, best practices in anesthesia care have been refined and implemented through evidence-based medicine, clinical guidelines, and multidisciplinary collaboration. This approach not only enhances patient safety and comfort but also significantly improves postoperative recovery outcomes, advancing the field of anesthesia care. Ongoing research and application of these methods will contribute to further optimization of the quality and outcomes of anesthesia care.

Conclusion

This review summarizes recent advancements and best practices in anesthesia care, including drug innovations, technological advances, improvements in anesthesia methods, the application of evidence-based medicine, clinical guidelines, and multidisciplinary collaboration. The focus on long-term recovery outcomes has been particularly significant, providing insights into reducing chronic complications, improving rehabilitation, and enhancing patient quality of life post-surgery. By systematically exploring advancements and practices in these areas, we found that personalized anesthesia care, multimodal analgesia, the development of novel anesthesia medications and techniques, and the optimization of multidisciplinary collaboration models are key factors in improving the quality of anesthesia care and improving patient outcomes. These innovations not only address immediate perioperative safety but also contribute to long-term recovery by mitigating risks of chronic pain, prolonged rehabilitation, and other postoperative complications. Integrating these advancements into clinical practice requires continued research and the development of comprehensive strategies to ensure their effective application across diverse patient populations. Future research should focus on further evaluating the impact of these innovations on long-term outcomes, including chronic pain management, functional recovery, and patient-reported outcomes such as satisfaction and quality of life. This holistic approach is essential for advancing anesthesia care, optimizing patient outcomes, and meeting the evolving demands of modern healthcare.

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