

Advances in the Clinical Application of Enhanced Recovery after Surgery (ERAS) Protocols in the Post-Anesthesia Care Unit (PACU)

Li Mu¹, Na Mao², Rui Xia^{1*}

¹Department of Anesthesiology, The First Affiliated Hospital of Yangtze University, Jingzhou, China

²Post-Anesthesia Care Unit, The First Affiliated Hospital of Yangtze University, Jingzhou, China

Email: *879560350@qq.com

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Abstract

Enhanced Recovery After Surgery (ERAS) has become a widely recognized perioperative management strategy aimed at minimizing physiological and psychological stress induced by disease, surgery, and anesthesia. It seeks to reduce postoperative complications, accelerate early recovery, and improve long-term outcomes. While ERAS protocols have been extensively implemented across the preoperative, intraoperative, and postoperative phases, their application in the post-anesthesia care unit (PACU) remains limited. Given the PACU's pivotal role in early postoperative management, extending ERAS principles into this phase has garnered increasing attention as a means to enhance patient safety and recovery efficiency. This review summarizes the current clinical practices and recent advances in applying ERAS strategies within the PACU. Key areas include the prevention and management of pain, postoperative nausea and vomiting (PONV), and the early identification and treatment of postoperative delirium (POD) and delayed emergence. Additionally, the potential role of non-pharmacological interventions—such as acupuncture, transcutaneous electrical nerve stimulation (TENS), and traditional Chinese medicine therapies—in supporting pharmacologic management is discussed. Technological advancements in PACU monitoring, including continuous end-tidal CO₂ monitoring, bedside ultrasonography, and wearable physiological sensors, have significantly improved the early detection of respiratory and hemodynamic instability and enhanced extubation safety. The review also highlights often-overlooked aspects such as proactive temperature management to prevent perioperative hypothermia and the importance of addressing postoperative thirst to improve patient comfort. Beyond clinical interventions, optimizing PACU workflows is emphasized, including standard-

*Corresponding author.

ized handovers, environmental noise control, proper patient positioning, and structured staff training to enhance care quality and operational efficiency. Establishing dedicated PACU quality management systems and fostering multidisciplinary collaboration are essential for ensuring consistent implementation of ERAS principles. In conclusion, integrating ERAS protocols into PACU management holds significant potential to promote early postoperative recovery and improve patient-centered outcomes. Further research and structured implementation are needed to define best practices and optimize resource utilization for continuous improvement in this critical phase of perioperative care.

Keywords

Enhanced Recovery After Surgery (ERAS), Post-Anesthesia Care Unit (PACU), Anesthesia Recovery Period

1. Introduction

Enhanced Recovery After Surgery (ERAS) is a modern, evidence-based approach to surgical care that focuses on helping patients recover faster and with fewer complications. By combining a set of best practices during the perioperative period—such as improved pain management, early mobilization, and better nutrition—ERAS aims to reduce the physical and emotional stress of surgery. These strategies not only lower the risk of postoperative complications but also shorten hospital stays and improve patients' overall satisfaction with their care [1]. The recovery phase after anesthesia is a particularly vulnerable time for patients, with a high risk of complications—some of which can be life-threatening. To help patients wake up safely and return to a stable, pre-anesthesia condition as quickly as possible, it is important to reduce complications in the post-anesthesia care unit (PACU), shorten recovery time, and ensure comfort. This highlights the need for ongoing improvements in PACU care and management practices. Since the introduction of ERAS in China in 2007 [2], although ERAS strategies have been widely implemented in the preoperative, intraoperative, and postoperative phases, their application in the post-anesthesia care unit (PACU) remains limited due to the relatively short duration of stay. Therefore, this review focuses on recent advances in the clinical application of ERAS principles in the PACU.

2. Reducing PACU Complications to Enhance Postoperative Recovery

2.1 Acute Postoperative Pain: Prevention and Management

Effective pain control after surgery is a key part of ERAS programs, helping patients recover more comfortably and quickly. However, pain remains a common issue in the post-anesthesia care unit (PACU), with studies reporting that 7.3% to 26.9% of patients experience pain during this period. Notably, about 1.42% of pa-

tients suffer from moderate to severe pain, which can negatively impact recovery and patient satisfaction [3]. If not properly managed, acute pain in the PACU can raise the likelihood of patients experiencing long-term or chronic postoperative pain [4]. In the PACU, tools like the Visual Analog Scale (VAS), Numeric Rating Scale (NRS), and the Wong-Baker Facial Pain Scale are often used to evaluate pain, but these methods rely heavily on patient self-report and are subjective. More objective alternatives include measuring the pupillary light reflex latency just before extubation [5], as well as using the APA5 acute pain scale within 15 minutes post-extubation, which assesses indicators such as facial expressions, body movements, verbal reactions, heart rate, and blood pressure [6].

Effective postoperative pain control relies on perioperative multimodal analgesia, with individualized pain management strategies playing a critical role in reducing postoperative inflammatory responses, alleviating anxiety, improving sleep quality, and minimizing complications. Although opioids remain the cornerstone of postoperative analgesia, concerns about their adverse effects have accelerated the shift toward opioid-sparing and even opioid-free analgesic regimens, along with the integration of nonpharmacological interventions as complementary approaches.

Central sensitization and peripheral sensitization are two principal mechanisms underlying postoperative pain. Opioids are primarily effective in preventing central sensitization. In contrast, nonsteroidal anti-inflammatory drugs (NSAIDs) and COX-2 selective inhibitors mitigate peripheral sensitization by inhibiting prostaglandin synthesis and reducing local inflammation. Regional anesthesia also contributes by blocking the activation of peripheral C and A-delta fibers. Together, these strategies help prevent peripheral pain amplification.

A recent study demonstrated that the use of regional anesthesia significantly reduces the risk of developing chronic postoperative pain (odds ratio 0.46; 95% confidence interval: 0.28 - 0.78; $p = 0.004$) [7]. Therefore, evidence-based non-opioid analgesic techniques—such as NSAIDs, epidural analgesia, ultrasound-guided regional nerve blocks, and local anesthetic infiltration—are strongly recommended components of postoperative pain protocols.

In addition, emerging complementary therapies from traditional Chinese medicine have shown promise in enhancing postoperative pain relief. Techniques such as local cold application, cheek acupuncture, and transcutaneous electrical nerve stimulation (TENS) have been identified as effective adjuncts within multimodal analgesia frameworks [8] [9]. Furthermore, preliminary studies suggest that aromatherapy [10] and music therapy [11] may provide additional benefits in optimizing postoperative pain control.

2.2. Prevention of Postoperative Nausea and Vomiting

Managing postoperative nausea and vomiting (PONV) is a key component of ERAS protocols. As early as 2016, the American Society for Enhanced Recovery recommended that all surgical patients receive PONV prevention measures dur-

ing the perioperative period [12]. While the overall incidence of PONV ranges from 20% to 40%, it occurs in about 9.6% of patients in the PACU [13]. Effective prevention not only shortens PACU stay but also helps reduce medical supply costs and eases the burden on healthcare staff [14]. Several factors increase a patient's risk of developing PONV, including being female, younger in age, a non-smoker, undergoing procedures such as cholecystectomy, laparoscopic, gynecological, or bariatric surgery, having a history of PONV or motion sickness, receiving inhaled anesthetics, and using opioids after surgery. Screening for PONV risk before surgery and creating individualized anesthesia plans and backup strategies for high-risk patients can help reduce the likelihood of PONV in the PACU.

For patients who develop PONV in the PACU, several rescue strategies are available:

1) Preoperative assessment of postoperative nausea and vomiting (PONV) risk is essential. For patients identified as low risk, prophylactic antiemetic therapy is generally not required during surgery. If intervention is deemed necessary, dexamethasone or a 5-hydroxytryptamine (5-HT₃) receptor antagonist is recommended as the first-line agent.

2) In high-risk patients, if prophylaxis with dexamethasone or a 5-HT₃ receptor antagonist has already been administered intraoperatively, and PONV still occurs, a rescue antiemetic with a different mechanism of action should be used. Recommended options include droperidol, diphenhydramine, promethazine, or metoclopramide. In addition, complementary therapies such as acupuncture and acupressure may be employed to enhance antiemetic efficacy [15].

3) If antiemetics have already been administered intraoperatively and in the PACU, but the patient continues to experience PONV, low-dose propofol or peppermint aromatherapy may be considered. Studies have shown that sub-hypnotic doses of propofol exert a brief antiemetic effect, with a median effective plasma concentration of approximately 0.343 mg/L [16].

4) If neuromuscular blockade reversal is required, sugammadex is the recommended agent [17].

2.3. Prevention and Management of Postoperative Delirium

Delirium is a sudden-onset mental disturbance marked by shifting levels of awareness and attention, confusion about time and place, memory loss, sensory misperceptions, and disordered thought processes [18]. It typically arises when the brain is unable to cope with physiological stressors or underlying triggers [19]. Research on patients undergoing non-cardiac surgery reported a 38% overall rate of delirium in the PACU, rising to 62% in elderly patients. Older age and cancer were recognized as significant risk factors for developing delirium [20]. Postoperative delirium has been linked to longer hospital stays, impaired functional recovery, cognitive deterioration, an increased risk of long-term dementia, and higher mortality rates. Timely recognition of patients at risk can greatly reduce the occurrence of delirium after surgery. It is estimated that around 40% of postoperative

delirium cases are both reversible and preventable in clinical practice [21].

Strategies to prevent postoperative delirium include:

- 1) Keeping the PACU environment calm and quiet;
- 2) Patiently communicating with patients and placing a clock where they can easily see it to help with orientation;
- 3) Playing recordings of a mother's voice for children in the PACU [22]; when feasible, allowing family members to visit early can support bedside care;
- 4) Encouraging early activity and oral intake while in the PACU;
- 5) Removing invasive or non-invasive monitoring as soon as respiratory and circulatory stability is ensured;
- 6) Training PACU nurses to be more aware of delirium, aiding in its early detection and management [23];

7) The European Society of Anaesthesiology and Intensive Care Medicine (ESAIC) does not recommend the use of dexmedetomidine or other pharmacologic agents for the prevention of postoperative delirium (POD). However, dexmedetomidine may be used for the treatment of POD, particularly in patients undergoing cardiac surgery [24]. Although dexmedetomidine shows therapeutic potential in managing postoperative delirium, its use requires caution due to associated adverse effects, such as sinus bradycardia and hypotension. In ICU patients requiring mechanical ventilation for more than 24 hours, early intravenous sedation with dexmedetomidine at a dose of 1 µg/kg/h (without a loading dose, and with maintenance titrated based on clinical response) may be associated with an increased 90-day mortality risk in patients aged ≤ 65 years, although the underlying mechanisms remain unclear [25].

2.4. Prevention of Delayed Emergence from Anesthesia

Delayed emergence from general anesthesia is defined as the failure to regain consciousness within 60 minutes after anesthetic discontinuation, during which the patient remains unresponsive to verbal cues or physical stimulation [26]. Thanks to advances in anesthetic drugs, improved monitoring technologies, and the growing emphasis on low-opioid anesthesia, the rate of delayed emergence has significantly declined. Effective prevention hinges on identifying high-risk patients early and taking proactive measures. Common risk factors include advanced age, young age, male sex, obesity, preexisting cognitive impairment, excessive intraoperative opioid use, history of alcohol use, respiratory dysfunction, hypothermia, prolonged anesthesia duration, and excessive fluid administration [27].

When multiple risk factors are present, anesthesiologists should tailor an optimized anesthetic strategy, employ appropriate monitoring tools, and maintain physiological homeostasis to reduce the risk of delayed recovery. In addition, studies in traditional Chinese medicine suggest that applying transcutaneous electrical stimulation to specific acupoints starting 20 minutes before anesthesia induction and continuing until the end of surgery [28], or administering higena-

mine—an extract from *Aconitum*—via intravenous infusion prior to induction [29], may help lower the risk of delayed emergence following surgery.

3. Application of Monitoring Technologies in the PACU

Recent advances in perioperative monitoring have enhanced anesthesiologists' focus on patient safety and contributed to improved quality of perioperative nursing care. In the PACU, non-intubated patients are particularly susceptible to respiratory complications, most commonly due to hypoventilation-induced hypoxemia. Oxygen saturation (SpO₂) may decline only after a significant delay following inadequate ventilation, whereas end-tidal carbon dioxide (PETCO₂) provides a more immediate and accurate reflection of ventilatory status. Continuous PETCO₂ or transcutaneous CO₂ monitoring is especially valuable for identifying early signs of hypoxemia in high-risk patients and has been associated with a reduced length of stay in the PACU [30] [31].

Bedside ultrasound has emerged as a portable and precise tool for both monitoring and intervention in the PACU. For instance, point-of-care cardiac ultrasound enables anesthesiologists to promptly detect pericardial effusion following transcatheter aortic valve replacement (TAVR), a potential cause of refractory hypotension in the PACU [32]. Timely extubation is essential for optimal recovery—extubating too early may result in complications such as CO₂ retention and hypoxemia, while prolonged intubation raises the risk of ventilator-associated pneumonia and diaphragmatic atrophy due to mechanical ventilation [33]. The diaphragm is crucial for spontaneous breathing, contributing to 60% - 80% of tidal volume [34]. Ultrasound measurements of diaphragmatic excursion (DE) and diaphragm thickening fraction (DTF) are reliable indicators for predicting extubation success [35]. Additionally, lung ultrasound allows early detection of postoperative atelectasis and impaired ventilation, and its diagnostic performance is comparable to chest CT in identifying pulmonary complications [36]. Mohamed and colleagues have developed a lightweight wearable patch sensor capable of collecting cardiac sounds, lung sounds, and ECG signals, which are then translated into real-time cardiopulmonary parameters. The device, weighing only 50 g with a compact size of 61 × 63 mm², offers a promising solution for continuous monitoring in the PACU [37].

4. Fast-Track Recovery Strategies in the PACU

4.1. Perioperative Temperature Control in the PACU

Perioperative hypothermia occurs in 4% to 70% of patients, with rates as high as 20% to 28% in the post-anesthesia care unit (PACU) [38] [39]. This condition is associated with a higher risk of surgical site infections, cardiac ischemic events, coagulation abnormalities, and delayed recovery.

Evidence from a prospective clinical study suggests that preoperative warming for just 15 minutes can significantly improve intraoperative core temperature and reduce the likelihood of unintended hypothermia [40]. In the PACU, active warm-

ing techniques—such as forced-air warming systems, fluid warmers, and adjusting room temperature—can be employed to maintain normothermia.

Complementary methods, including moxibustion, herbal plasters, and acupoint transcutaneous electrical stimulation, may also help regulate circulation and energy flow, thereby supporting temperature recovery [41].

4.2. Strategies for Relieving Postoperative Thirst in the PACU

Postoperative thirst is one of the most intense, common, and often overlooked subjective discomforts experienced by patients in the perioperative period [42]. Lee *et al.* reported that the incidence of postoperative thirst can reach up to 79.6%, with moderate to severe thirst affecting 53.2% to 69.8% of patients [43]. Compared to men, women tend to experience more persistent thirst discomfort over time following fluid restriction [44]. Notably, thirst has been shown to increase pain sensitivity [45], which may exacerbate anxiety and hinder recovery after surgery.

In PACU patients, postoperative thirst can be relieved by moistening the lips with cotton swabs, setting drinking intervals (e.g., every 15 minutes), and using oropharyngeal moisturizing sprays. Early oral hydration may be initiated as needed once patients are fully awake, stable, and have regained muscle strength and protective reflexes [46]. To reduce risks like reflux and aspiration, total fluid intake during the PACU stay should not exceed 0.5 ml/kg [47]. Small-volume early hydration also helps shorten postoperative ileus and promotes faster gastrointestinal recovery [48]. Therefore, PACU staff should actively address postoperative thirst rather than overlook this discomfort.

5. Optimizing Nursing Workflows in the PACU

Workflow optimization in the post-anesthesia care unit (PACU) is a key strategy for enhancing patient safety and care quality, and it also plays a critical role in addressing the increasing surgical volume and the growing diversity of patient needs.

Evidence suggests that streamlined nursing processes significantly promote safe and efficient postoperative recovery. The implementation of standardized handoff protocols effectively minimizes communication gaps and information loss, thereby improving the continuity and quality of perioperative care [49]. In the PACU, such structured handovers have been associated with higher nursing staff satisfaction, improved workflow efficiency, and reduced perioperative risks [50].

Equally important is the establishment of a strong culture of patient safety. Practical interventions—such as prioritizing the transfer of patients with shorter transport times during PACU congestion, reducing environmental noise, and adopting a 30-degree semi-Fowler's position for patients undergoing upper abdominal surgery—have been shown to lower the incidence of post-anesthetic complications, shorten recovery duration, and increase PACU throughput [51]-[53]. Clear procedural planning and enhanced interdisciplinary communication are essential components for improving the overall quality of perioperative care delivery.

Despite the implementation of standardized protocols, nursing errors remain prevalent—particularly within the high-stress, fast-paced environment of the post-anesthesia care unit (PACU). Evidence suggests that the incidence of missed nursing care can reach up to 78.1% [54], underscoring the need for thoughtful reflection on workforce training and staffing strategies. Amid rising patient volumes and resource constraints, it is essential to equip nurses with the skills necessary to manage acute conditions and complex clinical scenarios—an effort that is critical to maintaining high standards of care. Complementary to this, ongoing professional development and regular training initiatives empower nursing staff to adapt to evolving clinical demands and enhance their clinical proficiency.

6. Outlook

With the continuous development and widespread adoption of Enhanced Recovery After Surgery (ERAS) protocols, ERAS has been validated across multiple specialties as a feasible and effective perioperative management strategy with significant clinical benefits. As a critical component of perioperative anesthetic care, the Post-Anesthesia Care Unit (PACU) should fully integrate existing evidence-based ERAS practices and clinical research findings. This integration not only facilitates faster postoperative recovery and improves patient comfort, but also helps reduce the incidence of perioperative complications. However, the implementation of ERAS principles in the PACU remains challenging. First, the limited duration of patient stay in the PACU restricts the window for intervention, making it difficult to fully implement multiple ERAS measures. Second, an insufficient nurse-to-patient ratio and high workload hinder the delivery of individualized care and the execution of multidisciplinary collaboration. Furthermore, in some institutions, deficiencies in policy development, staff training, and financial investment undermine the effective implementation of clinical pathways, resulting in poor adherence. Collectively, these issues constitute major barriers to the widespread application of ERAS in the PACU setting.

To promote the clinical application of ERAS in the PACU, it is essential to establish a dedicated PACU quality management team, along with a scientific and standardized quality evaluation system, and to provide financial support to strengthen institutional quality control and reduce anesthesia recovery-related complications. In addition, healthcare providers should be encouraged to enhance their professional knowledge and actively participate in perioperative multidisciplinary collaboration, ultimately aiming to optimize resource utilization in the PACU and improve overall patient outcomes.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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