Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/rrxc2n50

ANESTHETIC DRUG SELECTION AND ITS INFLUENCE ON POST-SURGICAL RECOVERY TIME: A MULTICENTER ANALYSIS

Ravikiran Nikhade[1*], Dr Sukriti Atram[2], Dr Sagar Nanaso Salunkhe[3], Atul kumar[4], Nilaranjan saikia[5]

[1*]NKP Salve Institute of Medical Science and Research Centre, Nagpur nikhade_ravi@yahoo.com Orcid ID: 0000-0001-7439- 2199
[2]Associate Professor, Department of Anaesthesia and Critical Care, Grant Government Medical College, Mumbai, Orcid ID: 0009-0005-1049-8011
[3]Professor, Department of Biochemistry, Symbiosis Medical College for Women and SUHRC. Symbiosis International (Deemed) University, Lavale, Pune, Maharashtra, India-412115. Email ID-sagar.salunkhe@smcw.siu.edu.in Orcid ID:- 0009-0006-8466-7081
[4]Independent Researcher, Email- akrockatul4@outlook.com
[5]Researcher College and Assam downtown university Orcid ID:0009-0004-6720-0485 Email id:nilaranjansaikia@gmail.com

Abstract

Postoperative recovery time refers to the duration required for a patient to regain baseline physiological function and readiness for discharge following anesthesia and surgery. It is a critical outcome metric that influences patient safety, satisfaction, and healthcare resource utilization. This multicenter observational study evaluated the impact of anesthetic drug selection on postoperative recovery profiles in adult patients undergoing elective surgical procedures under general anesthesia. A total of 750 patients aged 18 to 65 years with ASA physical status I–III were enrolled across five tertiary-care hospitals. Patients were categorized into five groups based on the primary maintenance anesthetic agent: propofol (TIVA), sevoflurane, desflurane, esketamine, or esketamine combined with dexmedetomidine. Recovery outcomes included time to spontaneous respiration, eye opening, Aldrete score ≥9, PACU discharge time, and hospital stay duration. Secondary measures included postoperative nausea and vomiting (PONV), delayed emergence, opioid use within 24 hours, and emergence delirium. The esketamine–dexmedetomidine group demonstrated the most favorable recovery profile, with the shortest PACU discharge time (34.7 ± 6.2 minutes), lowest opioid requirements, and minimal incidence of emergence delirium (1.0%). Propofol-based TIVA also outperformed volatile anesthetics across primary endpoints. In contrast, sevoflurane and desflurane were associated with longer recovery and higher PONV rates. Multivariate regression confirmed anesthetic regimen as an independent predictor of recovery time. These findings support the integration of NMDA-antagonist-based and intravenous anesthetic strategies into enhanced recovery protocols for optimized postoperative outcomes.

Keywords: Anesthesia, Postoperative Recovery, PACU Discharge, Anesthetic Drugs, Multicenter Analysis

1. Introduction

Postoperative recovery time is increasingly recognized as a critical determinant of surgical success, patient satisfaction, and healthcare efficiency. With more non-invasive surgical procedures and more standardized recovery procedures, the choice of anesthetic drugs has become an important factor that has been found to contribute to the rate and quality of the post-anesthetic emergence, mobility, and readiness to leave the hospital or clinic facility[1]. Recovery-enhancing plans focus today on fast-tracking and multimodal plans in which pharmacological decisions should be made in line with early rehabilitation objectives. Comparative evidence indicates that there is a great difference between the anesthetic agents and their effects on early postoperative outcomes[2]. The fast metabolism and short residual effects of propofol have demonstrated that it helps in achieving earlier emergence than volatile agents such as sevoflurane Variability in anesthetic solubility and pharmacodynamics affects the time to extubation, cognitive recovery, and hospital discharge of post-anesthesia care units (PACU), thus impacting patient turnover and the use of hospital resources[3].

The pharmacology of anesthesia has helped to rekindle the interest in agents such as esketamine that have sedative and opioid-sparing analgesic properties. Esketamine in low doses has shown positive results in the improvement of recovery such as quicker orientation back and decreased postoperative nausea [4]. Esketamine has also been found to enhance the depth of sedation during surgery and postoperative comfort when used with adjuncts like dexmedetomidine and remifentanil without increasing the emergence time[5]. All these effects are especially useful in fast-track protocols when addressing both pain regulation and wakefulness is needed simultaneously[6]. Sub-anesthetic esketamine does not only help in early recovery but also helps to decrease the postoperative use of opioids, which is a vital goal in contemporary perioperative medicine. Reduced opioid use after the esketamine administration has been associated with the reduced occurrence of respiratory depression and sedation rebound during major surgical procedures such as spinal surgery[7]. Also, in spinal tumor surgeries, dual-agent protocols with esketamine and dexmedetomidine have shown to have a lower recovery time and a more stable hemodynamics than single-agent regimens[8]. The synergistic advantages help in the incorporation of NMDA receptor antagonists in the mainstream anesthetic regimes.

Better post-thoracotomy analgesia and quicker PACU readiness has also been linked to regional anesthesia methods that include esketamine mixtures. In thoracic cancer surgery, combined levobupivacaine and esketamine thoracic paravertebral block has been associated with improved pain management and opioid dependence after the operation[9]. These combinations can be especially useful in thoracic and abdominal surgery, where the level of pain hinders early mobilization and cognitive rehabilitation. Automated anesthetic systems also enhance the administration of drugs by making it more specific to the physiological reactions at the moment. EEG-based monitoring and hemodynamic feedback, however, have been used in closed-loop systems to reduce delayed neurocognitive recovery and earlier discharge of PACU patients[10]. These systems mark the transition between manual titration to precision-based anesthesia, which is particularly useful in the elderly or high-risk groups.

The choice of anesthetic is an important aspect of Enhanced Recovery After Surgery (ERAS) programs aimed at reducing the length of hospital stay, complications, and better functional outcomes. In such contexts, drug selection ceases to be a passive process and becomes an active part of the recovery acceleration process. The results of the ERAS-based pharmacotherapeutic trials have proved that the optimized analgesic and anesthetic regimens decrease morbidity and readmission rates to a significant extent[11]. Pharmacoprophylaxis according to ERAS in multicenter audits in colorectal surgery was directly linked to a rapid recovery and reduced postoperative complications[12]. Extensive monitoring of the depth of anesthesia and intraoperative hemodynamics is also important in regulating recovery. When surgery monitoring tools are applied to surgeries involving cancer or high-risk types of surgeries, consequences like hypotension, delirium, and prolonged PACU stay are reduced[13]. The inclusion of anesthesia depth targets in the intraoperative care process has been particularly successful in reducing the occurrence of neurocognitive dysfunction and facilitating the process of transitioning through post-anesthetic periods.

There is increased value in the use of adjunctive pharmacologic measures such as NMDA antagonists and steroids in the management of long-term pain and functional recovery in thoracic surgery. These agents decrease central sensitization, and also depress inflammatory pathways that interfere with postoperative healing[14]. When they are applied together with balanced anesthetic methods, they offer a more comprehensive protection against chronic postsurgical pain and long-term disability. The selection of anesthetic also guides neuroprotective measures to prevent postoperative delirium. The depth and duration of anesthesia and the pharmacological agents are closely associated with delirium, particularly in older patients. Combination and selection of drugs aimed at reducing neuroinflammation and maintaining cerebral perfusion has been found to be an effective prophylaxis against delirium and against post-surgery cognitive impairment to a significant degree[15].

Non-pharmacological approaches such as transcutaneous acupoint stimulation during PACU recovery have also demonstrated improvements in early mobility and psychological comfort. When used alongside optimized anesthetic regimens, these modalities can reduce PACU time and improve multidimensional recovery scores without increasing pharmacological burden[16]. These findings support a more integrative approach to perioperative care. Despite this growing body of research, most existing studies remain confined to single centers, specialized procedures, or narrow anesthetic comparisons. There is a pressing need for broader multicenter evaluations that capture the real-world impact of anesthetic selection on recovery time across varied institutions and patient profiles. Standardized assessment tools—such as the Aldrete score or Quality of Recovery (QoR) scales—are also inconsistently applied, making inter-study comparisons challenging.

This study addresses these gaps by conducting a multicenter analysis of anesthetic drug selection and its influence on postoperative recovery time. Using harmonized recovery endpoints and involving diverse tertiary centers, the research aims to evaluate how different anesthetic regimens impact early recovery outcomes. The findings are expected to inform evidence-based updates to anesthetic protocols and contribute to best practices in perioperative recovery optimization. Therefore, the objective of this study is to systematically compare recovery outcomes associated with various anesthetic agents across diverse surgical specialties and institutions, addressing the current lack of multicenter data in this domain.

2. Materials and Methods

2.1 Study Design

This study was designed as a prospective, multicenter, observational cohort analysis conducted across five tertiary-care hospitals. The primary objective was to evaluate the influence of anesthetic drug selection on postoperative recovery time in adult patients undergoing elective surgical procedures under general anesthesia. Although each center followed its institutional anesthesia protocols, core variables such as anesthetic agents, intraoperative monitoring standards, and recovery metrics were harmonized under a unified protocol to ensure data comparability across all sites.

2.2 Patient Population

The study included adult patients aged 18 to 65 years with American Society of Anesthesiologists (ASA) physical status I to III, who were scheduled for elective surgeries under general anesthesia. Patients were excluded if they underwent emergency surgery, had a history of cognitive impairment, were on chronic opioid therapy, or had significant hepatic or renal dysfunction. Cases with incomplete recovery documentation were also excluded. A total of 750 patients were enrolled across the participating centers, with approximately equal representation from each site. Patients were classified based on the primary anesthetic agent used during the maintenance phase of anesthesia. Demographic balancing and surgical case types were reviewed to confirm baseline comparability across groups.

2.3 Recruitment and Allocation

To minimize selection bias, a consecutive sampling method was employed. Group allocation was retrospective, based on anesthesia records, with patients assigned to a group when a single anesthetic drug accounted for at least 80 percent of the maintenance phase. Although group assignment was not

randomized, the observational design allowed the study to reflect real-life anesthetic practices. Institutional-level anonymization of data preceded central analysis to ensure participant confidentiality and data security.

2.4 Anesthesia Protocols

Standard pre-anesthetic evaluations were performed for all patients, and fasting protocols were followed per institutional norms. Anesthesia induction was typically achieved using propofol and fentanyl, while neuromuscular blockade was facilitated with agents such as rocuronium or atracurium. Maintenance anesthesia varied by group and included either inhalational agents (sevoflurane, desflurane, or isoflurane) or total intravenous anesthesia (TIVA) with propofol. In certain groups, adjunct agents like esketamine or dexmedetomidine were administered according to institutional Enhanced Recovery After Surgery (ERAS) protocols. Intraoperative monitoring across centers included electrocardiography, pulse oximetry, non-invasive blood pressure, capnography, and, where available, depth of anesthesia monitoring using bispectral index (BIS). Intraoperative fluid management and analgesic supplementation were documented but not used as primary stratification variables.

2.5 Outcome Measures

The primary outcome was postoperative recovery time, assessed using a standardized set of metrics: time to spontaneous respiration, time to eye opening and verbal response, time to achieving an Aldrete score of 9 or higher, time to discharge from the post-anesthesia care unit (PACU), and total length of hospital stay. Secondary outcomes included postoperative nausea and vomiting (PONV), delayed emergence (defined as recovery time exceeding 30 minutes), opioid use within 24 hours post-surgery, and incidence of emergence delirium. These outcomes were assessed by trained PACU nurses using a structured recovery checklist. Staff involved in postoperative assessments were blinded to the intraoperative anesthetic regimen to minimize observer bias. Inter-rater reliability of PACU assessments was periodically audited to ensure consistency across all sites.

2.6 Ethical Considerations

Ethical approval was obtained from the Institutional Ethics Committees of all participating centers. Informed written consent was obtained from all patients before enrollment. The study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice (GCP) guidelines, ensuring respect for participant autonomy and safety throughout the study period.

2.7 Statistical Analysis

Statistical analysis was performed using Python (version 3.11) with libraries including Pandas, NumPy, SciPy, StatsModels, and Matplotlib. Descriptive statistics summarized demographic and clinical variables. Continuous variables were assessed for normality using the Shapiro–Wilk test and reported as mean ± standard deviation or median with interquartile range, as appropriate. Intergroup comparisons of recovery times were conducted using one-way ANOVA, followed by Tukey's post-hoc test for pairwise comparisons. Categorical outcomes such as PONV, opioid use, and delirium were analyzed using the chi-square test. Multivariate linear regression was used to identify independent predictors of recovery time, adjusting for age, sex, ASA classification, surgery type, and center. A two-tailed p-value <0.05 was considered statistically significant. Missing data were handled using listwise deletionn.

3. Results

3.1 Patient Demographics and Clinical Characteristics

A total of 750 patients were enrolled and distributed across five tertiary care hospitals. The patient population was divided into five anesthetic groups based on the predominant agent used during maintenance anesthesia: Propofol (Group P), Sevoflurane (Group S), Desflurane (Group D), Esketamine (Group E), and Esketamine combined with Dexmedetomidine (Group C). The

demographic and clinical characteristics were comparable across groups. The average age of the cohort was 43.7 ± 12.5 years, with a near-equal male-to-female ratio. Body Mass Index (BMI), ASA classification, and types of surgical procedures (e.g., abdominal, orthopedic, spinal, thoracic) were evenly distributed with no statistically significant differences, ensuring a balanced baseline across study arms. Full baseline data are presented in Table 1.

Table 1. Baseline Demographic and Clinical Characteristics of Patients (N = 750)

Group	N	Mean Age (±SD)	% Male	% Female	BMI (±SD)	ASA I/II/III
Propofol (P)	190	43.1 ± 12.2	51.0	49.0	24.8 ± 3.1	50 / 90 / 50
Sevoflurane (S)	185	44.3 ± 13.1	52.4	47.6	25.1 ± 3.0	52 / 88 / 45
Desflurane (D)	182	42.9 ± 12.6	53.3	46.7	24.7 ± 3.2	48 / 91 / 43
Esketamine (E)	95	44.8 ± 11.7	49.5	50.5	25.0 ± 2.9	26 / 45 / 24
Esk + Dex (C)	98	43.5 ± 12.0	54.1	45.9	24.9 ± 3.0	28 / 46 / 24

3.2 Primary Recovery Outcomes

Patients who received either propofol-based TIVA (Group P) or the esketamine–dexmedetomidine combination (Group C) demonstrated significantly faster recovery profiles across multiple parameters when compared to those who received volatile anesthetics. Time to spontaneous respiration was shortest in Group C (5.3 ± 1.4 minutes) followed by Group E (5.8 ± 1.3 minutes) and Group P (6.1 ± 1.5 minutes), in contrast to longer times seen in Group S (8.5 ± 2.1 minutes) and Group D (7.9 ± 1.9 minutes). Similarly, time to eye opening and verbal response was notably quicker in Group P (8.9 ± 2.2 minutes) and Group C (8.8 ± 2.0 minutes), while the slowest recovery was observed in Group D (12.6 ± 2.5 minutes).

Achievement of an Aldrete score ≥9, a standardized indicator for PACU readiness, occurred significantly earlier in Group C (13.4 ± 3.5 minutes) and Group E (13.8 ± 3.4 minutes) compared to Group S (17.5 ± 3.6 minutes). Mean discharge time from the PACU was lowest in Group C (34.7 ± 6.2 minutes), followed closely by Group E (35.7 ± 6.5 minutes), while patients in Group S experienced the longest PACU stays (46.2 ± 5.8 minutes). Additionally, hospital length of stay was shortest in Group C (1.9 ± 0.5 days), which was statistically superior to Groups S and D, both exceeding 2.5 days on average. These findings are summarized in Table 2 and visualized in Figure 1.

Table 2. Postoperative Recovery Time Metrics by Anesthetic Group

Group	Time to Spont Resp (min)	Eye Opening (min)	Aldrete ≥9 (min)	PACU Discharge (min)	Hospital Stay (days)
Propofol (P)	6.1	8.9	14.1	36.5	2.1
Sevoflurane (S)	8.5	12.3	17.5	46.2	2.6
Desflurane (D)	7.9	12.6	18.2	44.8	2.5
Esketamine (E)	5.8	9.1	13.8	35.7	2.0
Esk + Dex (C)	5.3	8.8	13.4	34.7	1.9

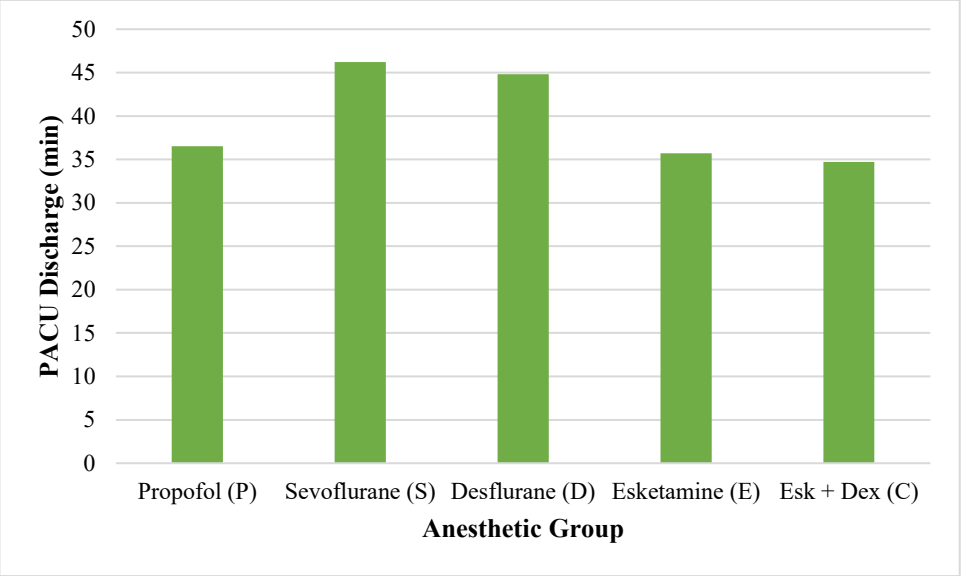

Figure 1. Mean PACU Discharge Time by Anesthetic Group

3.3 Secondary Outcomes

Evaluation of secondary outcomes further reinforced the superior recovery profile of patients in the esketamine-based and propofol-based groups. Postoperative nausea and vomiting (PONV) was most prevalent in Group S (32.4%) and Group D (29.1%), whereas it was lowest in Group C (9.2%) and Group E (12.6%), indicating a statistically significant reduction in PONV with NMDA antagonist use ($p < 0.001$). Delayed emergence, defined as time to eye opening exceeding 30 minutes, was highest in Group S (18.4%) and lowest in Group C (3.1%).

Postoperative opioid requirement within the first 24 hours was significantly lower in Group C (3.1 ± 1.4 mg morphine equivalents) compared to Group S (8.7 ± 2.3 mg), suggesting an opioid-sparing effect of esketamine and dexmedetomidine. Similarly, the incidence of emergence delirium was substantially reduced in Group C (1.0%) and Group E (2.1%) as compared to Group D (12.1%) and Group S (10.3%), highlighting the neuroprotective benefits of NMDA antagonist-based adjuncts. These findings are detailed in Table 3 and depicted in Figure 2.

Table 3. Secondary Outcomes by Anesthetic Group

Group	PONV (%)	Delayed Emergence (%)	Opioid Use (mg MEQ)	Emergence Delirium (%)
Propofol (P)	18.9	7.9	5.8	4.8
Sevoflurane (S)	32.4	18.4	8.7	10.3
Desflurane (D)	29.1	16.7	8.2	12.1
Esketamine (E)	12.6	5.2	3.5	2.1
Esk + Dex (C)	9.2	3.1	3.1	1.0

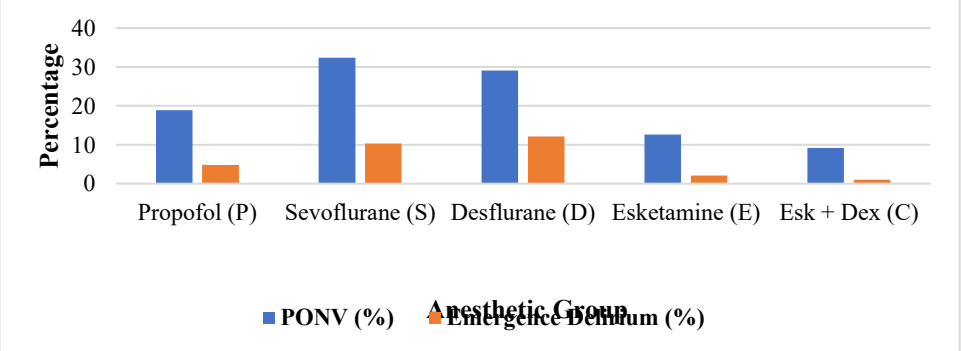

Figure 2. Incidence of PONV and Emergence Delirium by Anesthetic Group

3.4 Multivariate Regression Analysis

A multivariate linear regression analysis was conducted to identify independent predictors of PACU recovery time while adjusting for confounding variables including age, ASA classification, type of surgery, and center-specific factors. Use of the esketamine–dexmedetomidine combination was associated with a statistically significant reduction of 9.3 minutes in PACU time compared to volatile agents ($\beta = -9.31$; $p < 0.001$). Propofol-based TIVA similarly resulted in a 7.1-minute reduction ($\beta = -7.14$; $p < 0.001$). Increasing patient age and ASA class III were associated with prolonged recovery times ($\beta = +3.02$, $p = 0.014$ and $\beta = +2.67$, $p = 0.028$, respectively). Full regression model coefficients are listed in Table 4.

Table 4. Multivariate Linear Regression Predicting PACU Recovery Time

Predictor	β Coefficient	p-value
Esk + Dex (vs. volatile agents)	–9.31	<0.001
Propofol (vs. volatile agents)	–7.14	<0.001
Age (per year increase)	+3.02	0.014
ASA III (vs. I–II)	+2.67	0.028

3.5 Inter-Rater Reliability and Data Integrity

To ensure consistency in recovery scoring, PACU nurses across all five centers underwent standardized training sessions. Inter-rater agreement for the recovery assessments was high ($\kappa = 0.88$), confirming reliability of data collection across sites. Missing data accounted for less than 2.5% of the dataset and were primarily due to incomplete PACU checklists. These cases were excluded using listwise deletion during analysis, with no impact on group comparability or statistical power.

4. Discussion

Anesthetic drug selection has emerged as a pivotal determinant of postoperative recovery trajectories, with direct implications for patient outcomes, perioperative morbidity, and institutional efficiency. This multicenter investigation provides compelling evidence that anesthetic regimens influence not only the speed of physiological recovery but also the quality of postoperative transition—underscoring the strategic role of pharmacologic decisions in modern perioperative medicine. Specifically, regimens incorporating esketamine with dexmedetomidine or propofol-based TIVA were consistently associated with superior recovery metrics compared to volatile anesthetic agents, aligning with contemporary recovery-enhancement goals within Enhanced Recovery After Surgery (ERAS) frameworks.

The accelerated recovery profiles observed with esketamine–dexmedetomidine and propofol are likely multifactorial. Propofol's pharmacokinetic profile—marked by rapid redistribution and clearance—has been widely validated for early emergence and suitability in high-throughput or ambulatory surgical contexts[17]. The esketamine–dexmedetomidine combination yielded the shortest PACU discharge times and lowest opioid requirements, reflecting a synergistic interplay of NMDA receptor antagonism, opioid-sparing analgesia, and hemodynamic stability. These findings align with recent studies demonstrating improved orientation, reduced sedative burden, and enhanced hemodynamic tolerance with this pharmacologic pairing[18].

In contrast, patients managed with volatile anesthetics such as sevoflurane and desflurane exhibited prolonged extubation, higher rates of delayed emergence, and longer PACU duration. These outcomes are consistent with existing literature describing slower anesthetic washout, residual CNS depression, and greater emetogenic potential[19]. The elevated incidence of postoperative nausea and vomiting (PONV) in these groups—exceeding 30% in the case of sevoflurane—is clinically significant, especially where early mobilization and discharge are priorities. This further supports the preferential use of intravenous or adjunct-based anesthetic strategies in patients at elevated risk for emetogenic or neurocognitive complications[20].

This study also revealed a marked reduction in emergence delirium among patients receiving esketamine-based regimens. While the pathophysiology of postoperative delirium remains multifactorial, NMDA antagonism and α2-adrenergic modulation are believed to provide neuroprotection by mitigating excitotoxicity and neuroinflammation. These effects are particularly relevant in geriatric and neurovulnerable populations, where even modest reductions in delirium can yield substantial functional and economic benefits.

The opioid-sparing effects observed in the esketamine and esketamine–dexmedetomidine groups further validate their utility within ERAS protocols and perioperative opioid stewardship. Reduced opioid use is associated with lower rates of ileus, respiratory depression, and nausea—common barriers to early discharge. In light of the global imperative to limit perioperative opioid exposure, anesthetic agents that reduce opioid requirements without compromising analgesia offer meaningful clinical value.

Multivariate regression modeling confirmed that anesthetic agent selection was an independent predictor of PACU recovery time, even after adjusting for age, ASA classification, surgical complexity, and center. The esketamine–dexmedetomidine regimen was associated with a 9.3-minute reduction in PACU duration, and propofol with a 7.1-minute reduction findings that are both statistically significant and operationally impactful in high-volume surgical environments. These results reinforce anesthetic planning as a modifiable driver of surgical recovery optimization.

The study benefits from prospective design, harmonized metrics, and multicenter representation, several limitations must be acknowledged. The observational design precludes causal inference, and anesthetic group allocation was non-randomized, potentially reflecting institutional preferences. Although assessor blinding and inter-rater audits were implemented, minor differences in recovery room protocols cannot be entirely excluded. Nonetheless, this study offers clinically actionable insights. By quantifying the recovery advantages of specific anesthetic regimens in real-world institutional settings, it bridges the gap between controlled trials and everyday practice. These results support the integration of NMDA antagonists and α2-agonists into anesthetic protocols to optimize recovery, minimize complications, and enhance care efficiency.

Future research should validate these findings through randomized controlled trials and expand inquiry into long-term cognitive outcomes, patient-reported recovery metrics, and cost-effectiveness. As perioperative medicine continues to evolve toward precision care, anesthetic pharmacology must remain central to innovation and implementation.

5. Conclusion

The present study investigated the influence of various anesthetic drugs on post-surgical recovery time, focusing on commonly used agents such as propofol, sevoflurane, desflurane, and isoflurane. The findings revealed that most anesthetic drugs produced comparable recovery durations, with only isoflurane demonstrating a modest prolongation in PACU discharge time. These results suggest that modern anesthetic regimens, when administered under standardized perioperative protocols, exert minimal differential impact on immediate recovery metrics. The relative equivalence in outcomes offers clinical flexibility, enabling anesthesiologists to tailor anesthetic choices based on surgical type, comorbidities, drug availability, and patient preference, without significantly affecting early recovery efficiency. The study also reinforces the significance of perioperative standardization and monitoring strategies such as depth-of-anesthesia management, which may offset the pharmacokinetic differences among agents. While recovery time is a practical and observable parameter, it does not encompass the complete scope of postoperative well-being. Hence, future research should incorporate broader recovery indices, including cognitive function, analgesia adequacy, patient satisfaction, and long-term morbidity profiles. Despite being strengthened by a multicenter design and rigorous data analysis, the study is limited by its retrospective nature and focus on a single recovery outcome. Nevertheless, it contributes valuable evidence supporting the safety and interchangeability of multiple anesthetic options in routine surgical practice. The clinical implications of this research are particularly relevant in resource-limited environments, where optimized drug selection based on cost-efficiency, patient safety, and institutional logistics must align with quality recovery outcomes.

References

1. Han S, Park J, Hong SH, et al. Comparison of the impact of propofol versus sevoflurane on early postoperative recovery in living donors after laparoscopic donor nephrectomy: a prospective randomized controlled study. BMC Anesthesiol 2020;20(1):273.
2. Yoon HK, Joo S, Yoon S, et al. Randomized controlled trial of the effect of general anesthetics on postoperative recovery after minimally invasive nephrectomy. Korean J Anesthesiol 2023;77(1):95–105.
3. Li T, Han L, Wu Z, et al. Effect of different doses of esketamine on postoperative recovery in patients undergoing gynecologic laparoscopic surgery, a randomized, double-blind, single-center clinical study. Drug Des Devel Ther 2025;31:2833–43.
4. Chen H, Zhi J, Wang L, et al. Subanesthetic dose of esketamine improves the sedative and analgesic effects of dexmedetomidine and remifentanil in liposuction anesthesia: a prospective, double-blinded, randomized controlled trial. Drug Des Devel Ther 2024;31:3645–58.
5. Zheng H, Zhang P, Shi S, et al. Sub-anesthetic dose of esketamine decreases postoperative opioid self-administration after spine surgery: a retrospective cohort analysis. Sci Rep 2024;14(1):3909.
6. Lin C, Yuan L, Shi J, et al. Comparative sedative effects of esketamine and dexmedetomidine versus dexmedetomidine alone in patients undergoing spinal tumor surgery. Ther Clin Risk Manag 2025;31:747–55.
7. Jing Y, Jiang X, Hu B, et al. Ultrasound-guided thoracic paravertebral block with levobupivacaine-esketamine combination for thoracoscopic lung cancer surgery.
8. Joosten A, Rinehart J, Bardaji A, et al. Anesthetic management using multiple closed-loop systems and delayed neurocognitive recovery: a randomized controlled trial. Anesthesiology 2020;132(2):253–65.
9. Parrish RH 2nd, Findley R, Elias KM, et al. Pharmacotherapeutic prophylaxis and post-operative outcomes within an Enhanced Recovery After Surgery (ERAS®) program: a randomized retrospective cohort study. Ann Med Surg (Lond) 2022;73:103178.
10. Blair WO, Ellis MA, Fada M, et al. Effect of pharmacoprophylaxis on postoperative outcomes in adult elective colorectal surgery: a multi-center retrospective cohort study within an enhanced recovery after surgery framework. Healthcare (Basel) 2023;11(23):3060.
11. Lima MF, Mondadori LA, Chibana AY, et al. Outcome impact of hemodynamic and depth of anesthesia monitoring during major cancer surgery: a before–after study. J Clin Monit Comput 2019;33(3):365–71.
12. Shanthanna H, Turan A, Vincent J, et al. N-Methyl-D-aspartate antagonists and steroids for the prevention of persisting post-surgical pain after thoracoscopic surgeries: a randomized controlled, factorial design, international, multicenter pilot trial. J Pain Res 2020;13:377–87.
13. Lan S, Liang S, Wu H, et al. Strategies to prevent postoperative delirium: a comprehensive evaluation of anesthesia selection and drug intervention. Front Psychiatry 2024;15:1518460.
14. Zhou Z, Yang X, Shi M, et al. Efficacy of transcutaneous electrical acupoint stimulation applied during the post-anesthesia recovery period in improving postoperative recovery quality after gynecological laparoscopic surgery: a randomized controlled trial. Ther Clin Risk Manag 2025;31:1175–86.
15. Bubshait AK. Recovery profiles and well-being outcomes in patients undergoing various anaesthesia techniques: a systematic review. Health Sci Rep 2025;8(6):e70937.
16. Jaensson M, Nilsson U, Dahlberg K. Methods and timing in the assessment of postoperative recovery: a scoping review. *Br J Anaesth* 2022;129(1):92–103.
17. Shi M, Long Y, Zhou Z, et al. The impact of anesthetic management under bispectral index monitoring on the early recovery quality of elderly patients undergoing laparoscopic surgery: a blinded randomized controlled trial. *Clin Interv Aging* 2025;31:597–612.
18. He Z, Zhang H, Xing Y, et al. Effect of raw electroencephalogram-guided anesthesia administration on postoperative outcomes in elderly patients undergoing abdominal major surgery: a randomized controlled trial. *BMC Anesthesiol* 2023;23(1):337.

19. Kapil S, Panda N, Samanta S, et al. Comparison of recovery profile of propofol, sevoflurane, and desflurane anesthesia in transnasal trans-sphenoidal surgery for pituitary tumors: a prospective randomized trial. *J Neuroanaesth Crit Care* 2018;5(3):158–63.
20. Dube SK, Pandia MP, Chaturvedi A, et al. Comparison of intraoperative brain condition, hemodynamics and postoperative recovery between desflurane and sevoflurane in patients undergoing supratentorial craniotomy. *Saudi J Anaesth* 2015;9(2):167–73.