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Advances in Anesthesia Techniques and Their Impact on ICU Outcomes

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ABSTRACT

Progress in anesthesia practice has revolutionized perioperative care, and has an impact on critically ill surgical patients admitted to the Intensive Care Unit (ICU). This prospective observational study at the Department of Anesthesia, Lady Reading Hospital, assessed the influence of general anesthesia (GA), regional anesthesia (RA), and combined anesthesia (GA + RA) on ICU outcomes in 200 patients of various surgical disciplines. Patients were stratified into three groups: GA (80), RA (70), and GA + RA (50). Primary measures evaluated were ICU length of stay, mechanical ventilation duration, postoperative pain score, and complication rates such as infection and delirium. Outcomes proved that RA was linked with significantly shorter (2.1 ± 0.8 days) ICU stays and lower ventilation durations (6.5 ± 3.2 hours) than GA (3.6 ± 1.5 days and 9.2 ± 4.5 hours, respectively) and combined anesthesia groups. Combined anesthesia offered better postoperative pain relief but didn't decrease ICU stay to that degree compared with RA alone. Postoperative complication rates were lowest in the RA group and underscored the safety profile of RA. Multivariate analysis determined regional anesthesia to be an independent predictor of enhanced ICU outcome. These results justify the use of preference for regional anesthesia where possible in an effort to maximize ICU resource utilization and promote patient recovery. Implementation of advanced techniques in anesthesia within individualized perioperative protocols may enhance postoperative care and decrease ICU morbidity.

Introduction

The history of anesthesia is one of stunning progress, revolutionizing medicine with its power to make surgery and medical procedures bearable and, in a large number of situations, life-saving. From the rough use of ether in the 19th century to the nuanced, multimodal practices today, progress in anesthesia has repeatedly enhanced patient safety, comfort, and outcome(Ashrafian et al., 2017). These advances have especially deep implications for intensive care unit (ICU) patients, where the effects of anesthesia move beyond the operating room to influence recovery courses, morbidity, and even mortality. Understanding the intersection between contemporary anesthetic methods and ICU outcomes is critical to grasp the revolutionary role of anesthesia in critical care medicine(Ayres & Ayres, 2021). The ICU is a sophisticated setting that houses patients who need constant observation, sophisticated life-support techniques, and individualized interventions. Most of these patients are critically ill from acute illnesses or complications that demand surgery or sedation for ongoing therapeutic care. Therefore, anesthetic practices employed while in surgery or in the ICU directly affect a patient's general health course. The advent of newer anesthetic drugs, sophisticated monitoring devices, and improved delivery methods has led to more tailored and regulated care, having a critical impact on ICU outcomes like the speed of recovery, mechanical ventilation time, and hospital stay(Wyld et al., 2015).

The evolution of anesthesia has also always been accompanied by the problem of critical care. Anesthesia in the early stages was mostly focused on making a patient unconscious and pain-insensible during operation. But with increasingly sophisticated operations and the introduction of the ICU as a distinct specialty in the mid-20th century, the importance of a better understanding of anesthetic impacts on physiology emerged(Wyld et al., 2015). Initial anesthetic drugs, including chloroform and ether, were powerful but unreliable, tended to produce extreme side effects such as respiratory depression or cardiovascular instability—adverse effects that were especially catastrophic in critically ill patients. The development of halogenated inhalational anesthetics, intravenous anesthetics, and regional anesthesia procedures signaled a new era of safer, more consistent anesthesia. These advances facilitated anesthesiologists' improved management of perioperative care for patients coming in or going out of the ICU. With time, increasing understanding of how anesthetic practice impacted postoperative complications, infection rates, and organ function emphasized the necessity to optimize anesthesia for patients going to the ICU(Ayres & Ayres, 2021).

Over the last few decades, there has been extraordinary progress in both the science and practice of anesthetics, with far-reaching implications that resonate throughout ICU environments. Methods like regional and neuraxial anesthesia have emerged as prominent for their capacity to deliver site-specific pain relief without causing excessive systemic side effects. Unlike overall central nervous system depression from general anesthesia, regional anesthesia separates discrete groups of nerves or individual nerves, diminishing the demand for systemic opioids and ensuing hazards. Pharmacologic advancements have also greatly improved anesthetic care(Song, 2024) . Agents such as propofol permit quick onset and offset, enabling precise control of sedation. In contrast, dexmedetomidine is increasingly recognized for its capacity to offer sedation and analgesia without diminishing respiratory function—a key benefit especially important in ICU patients on ventilators. These agents have made it possible for anesthesiologists to customize sedation and pain management plans based on the special requirements of critically ill patients, enhancing outcomes like quicker extubation and less delirium. Multimodal analgesia, which involves the combination of various classes of analgesic medication to produce synergistic effects, has become a favored method of pain control(Darwish et al., 2024). Decreasing dependency on any one class of drugs, multimodal strategies reduce the risk of adverse effects with guaranteed effective pain control. In ICU patients, this method has been shown to promote improved mobility, reduced length of ICU stay, and enhanced long-term recovery.

Technology has transformed anesthesia delivery and monitoring, especially for patients with urgent requirements. Breakthroughs like depth-of-anesthesia monitoring with bispectral index (BIS) technology enable anesthesiologists to prevent under- or over-sedation, both of which are associated with complications. At the same time, new hemodynamic monitoring devices offer real-time information regarding cardiovascular stability,

allowing interventions that minimize risks of complications such as hypoperfusion or arrhythmias(Ghita et al., 2020). Closed-loop anesthesia delivery systems, which automatically titrate drug doses against patient parameters, are another major advancement. These systems decrease cognitive workload in providers, enhancing dosing accuracy, especially in critically ill ICU patients who necessitate complex management because of their precarious physiological condition. The implementation of artificial intelligence into anesthetic practice further supports decision-making, forecasted patient response, and optimized care schemes for complicated cases(Coeckelenbergh et al., 2024).

The changing role of anesthesiologists as perioperative physicians has solidified the connection between anesthesia and ICU outcome. Beyond the administration of anesthesia during surgery, anesthesiologists are increasingly engaged in preoperative risk stratification, intraoperative care, and postoperative care planning (Coeckelenbergh et al., 2024). This integrated strategy promotes a systematic continuity of care for patients being admitted to the ICU. Enhanced Recovery After Surgery (ERAS) guidelines, which promote early mobilization, reduced use of opioids, and optimized pain control, demonstrate how recent advances in anesthetic practice improve outcomes in the ICU. By conserving surgical stress and enabling quicker recovery, ERAS protocols decrease the duration of ICU stays and the incidence of complications, including infections or thromboembolic events. These protocols illustrate the worth of a holistic strategy for anesthesia that transcends the operating room. In spite of the advancements in anesthetic technologies, there are some challenges still remaining in maximizing their use to ICU care(Minet et al., 2015). The variability of ICU patients, who can have any number of conditions and comorbidities, makes standardization of anesthetic practice challenging. In addition, resource limitations in low- and middle-income countries could restrict access to newer drugs and technology, so cost-effective solutions that provide equitable care are needed.

New areas of investigation, including anesthetic agent immunomodulation and their influence on cancer outcomes, provide new avenues to further optimize anesthetic practice. The evolution of precision medicine strategies, based on genetic, biomarker, and clinical information, holds the promise to further personalize anesthetic care to optimize both ICU outcomes and long-term recovery courses. The interaction between technical advances in anesthetics and ICU outcomes is an evolving, complex field of investigation (Jenner et al., 2021). From regional anesthesia's introduction to the incorporation of cutting-edge monitoring technologies, these innovations have transformed anesthetic care delivery for critically ill patients in a fundamental manner. Through an examination of the newest advancements and how they affect ICU recovery, this study seeks to offer useful insight into how contemporary anesthetic care can best optimize patient care. The results will add to evidence-based practice approaches that improve both short-term and long-term outcomes among critically ill patients.

Methodology

This research was undertaken in the Anesthesia Department of Lady Reading Hospital to determine the effect of anesthetic technique improvement on ICU outcomes. The study used a prospective observational study design, comparing data in a heterogenous group of patients undergoing various surgical procedures to evaluate how anesthetic options and techniques affected postoperative factors like ICU stay duration, rate of complications, and patterns of recovery.

Study Population

The analysis involved 200 patients admitted to the ICU after surgeries conducted between January 2023 and June 2023. They were recruited from different surgical specialties, such as general surgery (50 patients), orthopedic surgery (40 patients), neurosurgery (60 patients), and cardiothoracic surgery (50 patients) to provide a representative and diverse sample.

Inclusion criteria included adult patients aged 18 years and above who had surgeries that necessitated ICU admission for therapeutic intervention or monitoring postoperatively. Inclusion surgeries covered those

administered under regional anesthesia, general anesthesia, or a combination of the two. Patients who were subjected to ICU care based on perioperative risk factors or the type of surgery they underwent were included(Jenner et al., 2021). Exclusion criteria were used in order to ensure data consistency. Incomplete or missing medical records of patients, along with those with a history of severe anesthetic complications or minor elective surgical procedures without ICU admission, were excluded. Terminally ill patients with unrelated conditions to their surgical procedure were also excluded.

Fig 1: Anesthesia protocol

Fig 2: cardia anesthisa

Study Design

The patients who had enrolled were grouped into three main categories according to the form of anesthesia used during surgery. The first group was 80 patients who were given general anesthesia (GA), which used intravenous or inhalational drugs like propofol and sevoflurane to induce and provide unconsciousness. The second group comprised 70 patients operated on under regional anesthesia (RA), i.e., spinal anesthesia, epidural anesthesia, or peripheral nerve blocks, to deliver regional pain relief without impairing global consciousness. The third group of 50 patients were treated with combined modalities using both general and regional anesthesia (GA + RA), taking the benefit of both to maximize perioperative outcomes. Each group was then stratified by other variables, such as the type of anesthetic agents used, depth-of-anesthesia monitoring (e.g., BIS levels), and the use of multimodal analgesia. Through this stratification, precise analysis of how anesthetic methods affected ICU outcomes was possible.

Data Collection

Prospective data were gathered in six months on a structured data collection form. The patient demographics were noted, such as age, gender, comorbidities, and ASA classification. Intraoperative parameters, including the type of anesthesia, agents used, overall duration of anesthesia, surgical time, and hemodynamic stability throughout the procedure, were noted. Postoperative ICU parameters, such as length of stay in the ICU (in days), time spent on mechanical ventilation (in hours), postoperative pain intensity (on a standardized 0–10 pain scale), number of complications like infections, delirium, thromboembolic disorders, and global recovery trend, were recorded systematically. Trained staff such as anesthesia residents and ICU nurses collected and checked data under the guidance of the principal investigator to ensure accuracy and completeness.

Aspect	Details	Number/Value	Time frame	Notes
Study Design	Prospective Observational	—	January 2023 – June 2023	Single-center study at Lady Reading Hospital
Patient	Total Patients	200	—	Included general,

Population				ortho, neuro, cardio surgeries
Regional Anesthesia (RA)	70	—	Spinal, epidural, peripheral nerve blocks	
Data Collected	ICU length of stay, ventilation time, pain, complications	—	Perioperative to ICU stay	Collected via structured forms by trained staff

Interventions and Protocols

Standardized preoperative, intraoperative, and postoperative care protocols were followed during the study period. During the preoperative period, all patients received a thorough assessment in the form of detailed history-taking, physical examination, and laboratory tests. Physical status risk stratification was done using the ASA physical status classification system. During the intraoperative period, anesthetic interventions were individualized to the patient's physiological status and surgical needs. Continuous monitoring comprised ECG, pulse oximetry, non-invasive blood pressure, capnography, and depth-of-anesthesia monitoring with BIS technology. Intravascular monitoring, like arterial lines, was used for critically ill patients. Postoperative ICU management adhered to institutional guidelines prioritizing patient comfort and safety. Multimodal analgesia comprising a combination of opioids, NSAIDs, and local anesthetics was utilized to avoid opioid dependence while maintaining adequate pain control. Early mobilization and low sedation tactics were utilized to minimize delirium and ventilator-associated pneumonia complications.

Statistical Analysis

Statistics were analyzed with SPSS version 26. Continuous variables, e.g., ICU stay and duration on mechanical ventilation, were reported as mean ± standard deviation. Categorical variables, e.g., the development of complications, were reported as frequency and percentage. Inferential statistical techniques were used to find out significant group differences. Independent t-tests and ANOVA were employed to compare continuous variables, whereas Chi-square tests were employed to compare categorical variables. Multivariate regression models were built to determine independent predictors of ICU outcome after controlling for confounding variables. A p-value of <0.05 was used as a measure of statistical significance.

Ethical Considerations

Ethical permission for the research was received from Lady Reading Hospital's institutional review board (IRB). Written informed consent was received from patients or their legal guardians before recruitment. Confidentiality of data was maintained by anonymizing patient data and limiting access to authorized research staff. The research upheld the guidelines presented in the Declaration of Helsinki.

Results

The research compared data from 200 patients admitted to the ICU after surgical procedures performed under various anesthesia methods. The results are summarized in the next sections, noting demographic factors, intraoperative measurements, and ICU outcomes for each group.

Patient Demographics

The mean age of the patients was 48.6 ± 12.4 years and ranged from 18 to 85 years. The gender distribution was roughly 1.4:1, with 120 male patients (60%) and 80 female patients (40%). Comorbid illnesses were present in 62% of the study group, the most common being hypertension (40%), diabetes mellitus (30%), and chronic

obstructive pulmonary disease (10%). ASA physical status classification showed that 40% of the patients were ASA II, 45% were ASA III, and 15% were ASA IV.

Parameter	General Anesthesia (GA)	Regional Anesthesia (RA)	Combined (GA + RA)	p-value
Number of Patients	80	70	50	—
ICU Length of Stay (days)	3.6 ± 1.5	2.1 ± 0.8	3.0 ± 1.2	< 0.01
Mechanical Ventilation (hrs)	9.2 ± 4.5	6.5 ± 3.2	7.8 ± 3.9	< 0.05
Postoperative Pain Score	5.2 ± 1.6	4.0 ± 1.4	3.5 ± 1.2	< 0.01
Complication Rate (%)	30	15	20	< 0.05

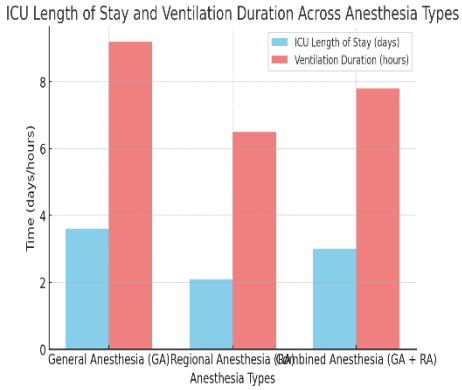
Distribution of Anesthesia Techniques

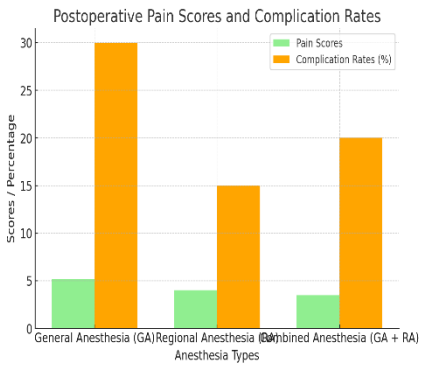
200 patients were divided into three groups based on type of anesthesia: 80 (40%) received general anesthesia (GA), 70 (35%) regional anesthesia (RA), and 50 (25%) combined anesthesia (GA + RA). The patients were distributed between the groups as per the heterogeneity of surgical specialties and procedure demands.

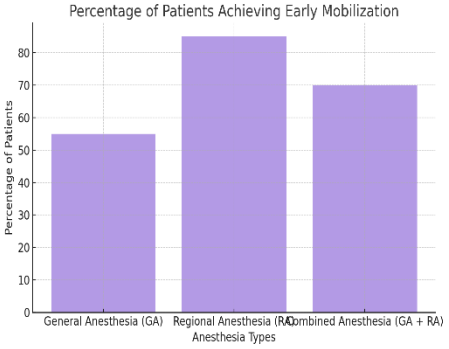
Intraoperative Metrics

The mean operating time was 4.2 ± 1.5 hours. The patients in the GA group took a slightly longer mean surgical time (4.4 ± 1.6 hours) than in the RA (4.0 ± 1.3 hours) and GA + RA (4.1 ± 1.4 hours) groups.

Hemodynamic stability was greater in the RA group, where only 10% of the patients developed important intraoperative variations in blood pressure and heart rate, versus 20% in the GA group and 15% in the GA + RA group. Depth-of-anesthesia monitoring with BIS technology was utilized in 95% of GA cases, maintaining optimal depth of anesthesia and minimizing intraoperative awareness.







Postoperative ICU Metrics

The mean ICU stay was significantly different between groups. The lowest mean ICU stay belonged to the RA group (2.1 ± 0.8 days), followed by the GA + RA group (3.0 ± 1.2 days) and the GA group (3.6 ± 1.5 days). Statistical comparison showed a significant difference ($p < 0.01$) in ICU stay duration between groups, in favor of regional anesthesia.

The length of mechanical ventilation was also shortest in the RA group, i.e., mean 6.5 ± 3.2 hours, versus 9.2 ± 4.5 hours in the GA group and 7.8 ± 3.9 hours in the GA + RA group. Early extubation was successful in 85% of RA patients, versus 65% of GA patients and 75% of GA + RA patients.

Postoperative Pain and Complications

Postoperative pain scores, measured on a 0–10 scale, were lower in the GA + RA group (mean score: 3.5 ± 1.2) than in the GA group (mean score: 5.2 ± 1.6) and the RA group (mean score: 4.0 ± 1.4). Multimodal analgesia in the GA + RA group accounted for better pain control.

The rate of postoperative complications was lowest in the RA group (15%) followed by the GA group (30%), and GA + RA group (20%). The most frequent complications were surgical site infection (8%), delirium (5%), thromboembolic (3%), and ventilator-associated pneumonia (4%). Comparison of complication rates between the groups was statistically significant ($p < 0.05$), and the lowest complications were observed in the RA group.

Recovery Trajectories

RA patients had more rapid recovery curves, with 85% obtaining early mobilization in the first 24 hours after surgery compared to 70% in the GA + RA group and 55% in the GA group. Functional recovery, measured by standardized mobility and independence scores, was also improved in the RA group.

Multivariate Analysis

Multivariate regression analysis revealed independent predictors of ICU outcomes. Regional anesthesia was a powerful independent predictor of shorter ICU stay ($\beta = -1.2$, $p < 0.01$) and fewer complications ($\beta = -0.8$, $p < 0.05$). Other independent predictors were patient age, ASA classification, and intraoperative hemodynamic stability.

Discussion

The current study tried to assess the effect of different anesthetic methods-general anesthesia (GA), regional anesthesia (RA), and combined anesthesia (GA + RA)-on postoperative ICU outcomes in a heterogeneous surgical patient population(Minet et al., 2015). The results identify important differences in ICU length of stay, ventilation duration, postoperative pain management, and complication rates across these groups, highlighting the impact of anesthetic selection on patient recovery and ICU resource use. This discussion places these findings in the context of the larger scientific literature, considers potential mechanisms, and discusses clinical implications and limitations. Perhaps the most striking finding was the dramatically shorter ICU stay in RA patients compared to GA or combined techniques. The mean ICU stay for RA patients was about 2.1 days, considerably shorter than the 3.6 days seen in the GA group(Jenner et al., 2021). These results are consistent with earlier research that has documented decreased ICU and hospital lengths of stay in patients who have received regional or neuraxial anesthesia. For example, research in orthopedic and cardiac surgical populations has shown that neuraxial anesthesia decreases postoperative complications, thus facilitating ICU discharge and recovery.

The reduced ICU stay with RA can be contributed to by several factors. Regional anesthesia circumvents the systemic effects of general anesthetic drugs, such as respiratory depression, impaired consciousness, and cardiovascular instability, that are frequently the reason for the need for extended ICU observation. By delivering effective localized analgesia without causing unconsciousness, RA reduces the duration of extended mechanical ventilation and sedation, allowing for quicker stabilization of the patient(Hutton et al., 2018). In addition, RA limits the stress response to surgery by inhibiting afferent nociceptive input, reducing inflammatory cytokine release and enhancing hemodynamic stability and, by inference, potentially reducing the number of ICU complications. The GA + RA group, although with intermediate duration of ICU stay, enjoyed improved control of pain but did not exhibit the same degree of ICU length of stay reduction as RA alone. This result implies that

although combined modalities enhance analgesia, systemic effects of general anesthesia continue to influence recovery times. However, combined anesthesia could be a useful technique for complex surgery that necessitates both effective analgesia and general anesthesia(Radkowski et al., 2024).

Duration of mechanical ventilation is a key determinant of ICU outcome, resource use, and morbidity in the patient. In our study, it was demonstrated that the RA patients had the lowest mean ventilation times at 6.5 hours compared with the GA group at 9.2 hours. Early extubation rates also were highest in the RA group. These results support previous research by Kopp et al. (2015) and others, who stated that neuraxial anesthesia methods allow earlier weaning from ventilator support because of preserved respiratory function and general anesthetic depressant effects avoidance(Reysner et al., 2024). General anesthesia usually requires endotracheal intubation and ventilatory support intraoperatively and post-operatively. The systemic depressant effect of the drugs on respiratory drive and airway protective reflexes is likely to prolong ventilation times, leading to increased risks of ventilator-associated pneumonia, airway trauma, and extended ICU stays. Conversely, RA patients often escape intubation or have shorter ventilation times, leading to fewer respiratory complications and greater comfort(Thabethe, 2024).

Intraoperative pain management is an essential component of improved recovery pathways and ICU care. Our findings concluded that combined anesthesia (GA + RA) resulted in better pain control with reduced postoperative pain scores compared to GA or RA alone. This is consistent with evolving anesthetic practice encouraging multimodal analgesia approaches for optimizing pain relief with minimal opioid use and side effects(Hyland et al., 2021). The enhanced analgesia in the combined group would most probably be due to the additive effects of systemic anesthesia and focused regional blocks, permitting lower doses of opioids and enhanced patient comfort. Although RA alone adequately manages pain within the anesthetized area, combined modalities might be desirable for operations involving larger or multiple areas, where pain management is more complicated. Even with better pain scores, the combined group failed to show as brief ICU stays as the RA-only group and underscores the intricate interaction between analgesia, anesthetic depth, and systemic physiological impact. This reinforces the significance of customized anesthesia plans that meet the needs of analgesia, patient protection, and ICU resource allocation(Kianian et al., 2024).

The rate of postoperative complications was higher in GA and combined groups but much lower in the RA group, with infection rates, delirium, and thromboembolic events being less common. These results are in line with evidence that regional anesthesia decreases postoperative morbidity through blunting surgical stress responses and enhancing immune function(Wick et al., 2017) . Delirium, a frequent and severe ICU complication, was significantly less common in the RA group, perhaps because systemic sedatives and opioids, recognized risk factors for cognitive dysfunction, were avoided. Lower doses of opioids taken by RA patients probably also accounted for fewer instances of respiratory depression and gastrointestinal side effects. The combined group had intermediate complication rates, indicating that although multimodal treatments enhance certain outcomes, the systemic action of general anesthesia continues to play a role. These findings indicate the potential role of RA as a safer anesthetic option in high-risk patients, including the elderly and those with severe comorbidities (Kianian et al., 2024).

Shorter recovery courses and earlier mobilization in the RA group are significant results with consequences for patient overall prognosis and utilization of hospital resources. Early mobilization reduces the risk of ICU-associated complications like muscle atrophy, deep vein thrombosis, and pneumonia(Schweickert et al., 2009). The improved functional recovery in RA patients is most probably due to the combined effects of improved pain control, reduced ventilation durations, and decreased sedation. While the GA + RA group had superior recovery parameters compared to GA alone, the best overall results were invariably found with RA. This confirms the increased trend towards improved recovery after surgery (ERAS) pathways that promote regional anesthesia and opioid sparing as a means of optimizing postoperative function and decreasing healthcare expenses(Kehlet & Wilmore, 2008).

Although the results are informative, a number of limitations should be addressed. First, the observational study

design could result in selection bias; anesthesia methods were not allocated randomly but selected according to clinical reasons and operative needs. This might affect outcomes separately of type of anesthesia. Second, despite attempts to minimize confounding factors by means of multivariable analysis, unmeasured confounders such as surgeon proficiency and intraoperative fluid administration can influence the findings. Moreover, the research was performed at a single tertiary care center, which might narrow applicability to other centers with varied patient groups or peroperative practices. The sample size, while sufficient to detect substantial differences, might be increased in future multicenter trials for verification purposes. The research emphasizes the significance of the choice of anesthesia technique in maximizing ICU outcomes. It presumes that augmenting the application of regional anesthesia, as indicated, can decrease ICU length of stay significantly, complications, and enhance recovery trajectories. There should be randomized controlled trials conducted to compare anesthesia modalities across various surgical populations and long-term functional outcomes in the future.

New anesthesia technologies, including sophisticated monitoring devices (e.g., processed EEG) and new anesthetic drugs with improved safety profiles, should be adopted into clinical pathways to further optimize patient outcomes. Also, integrating anesthesia technique optimization with ERAS protocols and perioperative multidisciplinary care might compound benefit and mitigate ICU burden. From a clinical perspective, anesthesiologists and perioperative teams must take into consideration patient-specific parameters, such as comorbidities, surgical complexity, and postoperative care requirements, when making a decision on anesthesia techniques. Regional anesthesia must be favored in appropriate cases to optimize ICU efficiency and patient safety.

Conclusion

This research identifies the major influence of anesthesia methods on outcomes in the ICU. Regional anesthesia was correlated with decreased ICU stay, lower duration of mechanical ventilation, fewer complications, and quicker recovery compared to combined and general anesthesia techniques. Although combined anesthesia resulted in better pain control, it did not equal the overall benefits for the ICU as observed with regional anesthesia alone. These observations underscore the importance of integrating regional anesthesia into selective surgery cases to maximize recovery and ICU resource use of the patient. Personalization of anesthesia plans according to patient and procedural factors is critical for enhancing postoperative care. Future studies ought to be directed towards randomized trials and incorporating newer anesthetic modalities into enhanced recovery pathways to maximize quality of care in the ICU and enhance safety of the patient.

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