

Two paths, one goal—uniting regional and general anesthesia for optimal surgical care: a narrative review

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The integration of regional anesthesia (RA) with general anesthesia (GA) has become a central component of multimodal strategies to improve perioperative pain management. This approach not only enhances analgesic efficacy but also reduces opioid requirements and mitigates opioid-related adverse effects. By targeting peripheral or neuraxial nociceptive pathways, RA attenuates the surgical stress response and decreases central sensitization, complementing the systemic actions of GA. The combined application of RA and GA has shown substantial benefits across a wide range of surgical procedures, including abdominal, thoracic, orthopedic, and pediatric operations. Reported advantages include improved hemodynamic stability, enhanced pulmonary function, earlier ambulation, faster gastrointestinal recovery, and greater patient satisfaction. Moreover, recent evidence indicates a positive association between effective postoperative pain control and long-term outcomes, such as reduced incidence of persistent postsurgical pain, better functional independence, and even improved immune function and survival following cancer surgery. The development of sustained-release local anesthetic delivery systems, which provide localized and prolonged analgesia, further extends the benefits of RA-GA integration into the postoperative period. This review summarizes the mechanistic rationale, clinical applications, and future directions of RA-GA combinations in modern surgical care, with special emphasis on their role in enhanced recovery after surgery protocols.

Keywords: Analgesia; Conduction anesthesia; General anesthesia; Enhanced recovery after surgery; Postoperative pain

Introduction

Background

Surgical procedures elicit a complex physiological stress response involving nociceptive signaling, neuroendocrine activation, and inflammatory cascades, all of which can negatively affect postoperative recovery. General anesthesia (GA), although indispensable for inducing unconsciousness and immobility, provides limited site-specific analgesia and frequently necessitates the use of high-dose opioids. These opioids are associated with a broad range of adverse effects, including respiratory depression, nausea, ileus, urinary retention, and opioid-induced hyperalgesia, all of which may delay recovery and diminish patient satisfaction [1,2].

Regional anesthesia (RA), when integrated into anesthetic management, enables targeted blockade of nociceptive pathways at peripheral or neuraxial sites. When combined with GA, RA decreases intraoperative opioid and anesthetic requirements, improves hemodynamic stability, and facilitates early mobilization.

For these reasons, RA has become a cornerstone of enhanced recovery after surgery (ERAS) protocols [3,4].

Recent pharmacological innovations have introduced sustained-release local anesthetic delivery systems designed to prolong analgesia while limiting systemic exposure [5]. Liposomal bupivacaine, for example, employs multivesicular liposomes to sustain peripheral nerve blockade for up to 72 hours [6]. Other investigational platforms, including polymeric microspheres, nanofiber scaffolds, and hydrogel-based carriers, aim to optimize controlled drug release at the target site. These systems are designed to maintain therapeutic concentrations locally, decrease central sensitization, and enhance the effectiveness of multimodal analgesia when combined with GA.

The quality of acute postoperative pain control is increasingly recognized as a determinant of long-term outcomes. Poorly managed acute pain is a known risk factor for persistent postsurgical pain (PPSP), which develops in 30%–50% of patients undergoing major surgery [7]. PPSP is associated with functional limitations,

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reduced quality of life, and psychological comorbidities such as depression and anxiety. Inadequate pain control also elevates the risk of complications, including venous thromboembolism, pulmonary dysfunction, and impaired wound healing, ultimately prolonging hospitalization and increasing healthcare costs.

Emerging evidence further suggests that optimized perioperative analgesia may improve long-term health outcomes, including cancer-related survival and reduced tumor recurrence [8]. These benefits are thought to arise from decreased systemic inflammation, preservation of immune surveillance—particularly through natural killer (NK) cell activity—and attenuation of the immunosuppressive effects of opioids and surgical stress [9,10].

Accordingly, the integration of RA with GA not only addresses the limitations of GA alone but also supports both immediate recovery and favorable long-term clinical outcomes.

Objectives

This review outlines the physiological rationale, clinical benefits, technical applications, and future directions of combining RA with GA as a comprehensive and evidence-based perioperative strategy.

Ethics statement

This was a literature-based study; therefore, neither approval by the institutional review board nor informed consent was required.

Mechanisms and rationale for combined use

RA exerts its principal analgesic effect by selectively blocking nociceptive signal transmission at the level of peripheral nerves, nerve plexuses, or the spinal cord—particularly the dorsal horn. This targeted interruption of afferent input prevents amplification of pain signals within the central nervous system, thereby lowering the risk of central sensitization and the development of hyperalgesia or allodynia [11]. A key mechanism involves attenuation of the wind-up phenomenon through inhibition of excitatory neurotransmitter release—such as glutamate and substance P—and downregulation of NMDA receptor activity. When combined with GA, which primarily acts at the cortical level to suppress pain perception and consciousness, this multimodal approach provides synergistic analgesia covering both peripheral and central pathways, thereby ensuring broad-spectrum antinociception throughout the perioperative period [12,13].

Beyond analgesia, the combined application of RA and GA offers additional physiological advantages. By blocking nociceptive

input at its source, RA dampens activation of the hypothalamic-pituitary-adrenal axis and blunts perioperative surges in catecholamines (epinephrine and norepinephrine) and cortisol. This neuroendocrine modulation enhances intraoperative hemodynamic stability, decreases myocardial oxygen demand, and reduces the risk of arrhythmias and ischemia; these effects are particularly valuable in cardiac patients and older adults. Neuraxial techniques such as spinal or epidural anesthesia also improve pulmonary function by reducing systemic opioid requirements and preventing opioid-induced respiratory depression [14]. Consequently, diaphragmatic function is better preserved, atelectasis is minimized, and gas exchange is improved. In addition, RA has been associated with favorable immunomodulatory effects, including reduced leukocyte activation and attenuation of the inflammatory response, which may contribute to improved wound healing and preserved immune competence during the postoperative period [15].

One of the most consistently documented benefits of combining RA with GA is its opioid-sparing effect. Depending on the surgical procedure and block type (e.g., peripheral nerve block, epidural), intraoperative and postoperative opioid consumption may be reduced by 30%–50%. This reduction lowers the incidence of opioid-related side effects—including postoperative nausea and vomiting, ileus, urinary retention, and sedation—and may also decrease the risk of opioid-induced hyperalgesia and prolonged opioid use after discharge. For example, a systematic review and meta-analysis found that the erector spinae plane (ESP) block in laparoscopic abdominal surgery reduced opioid use (mean difference, -5.95 mg; 95% confidence interval [CI], -8.86 to -3.04 mg), as well as the incidence of nausea (relative risk [RR], 0.38; 95% CI, 0.25–0.60; $P < 0.001$) and vomiting (RR, 0.32; 95% CI, 0.17–0.63; $P = 0.0009$) [16]. Another study reported that ultrasound-guided posterior quadratus lumborum (QL) block in abdominal surgery decreased postoperative opioid consumption at 24 hours (standardized mean difference, -0.45 ; 95% CI, -0.86 to -0.03) [17].

Enhanced recovery is further supported by accelerated gastrointestinal function, earlier mobilization, and a lower incidence of postoperative delirium—particularly in geriatric patients [3]. Multimodal analgesic strategies incorporating RA have been linked to shorter hospital stays, quicker return to baseline functional status, and higher patient satisfaction scores [18]. Importantly, RA may also reduce the risk of chronic postsurgical pain by mitigating early central sensitization and interrupting ongoing nociceptive input during the perioperative period [19].

Techniques of regional anesthesia adjunct to general anesthesia

RA, when combined with GA, constitutes a cornerstone of multi-modal analgesia and ERAS protocols [3,20]. RA techniques are broadly classified into neuraxial and peripheral blocks, each offering targeted analgesia, reducing systemic opioid requirements, and minimizing perioperative complications [21-24]. Table 1 summarizes regional anesthetic techniques applicable across surgical contexts.

Spinal anesthesia involves intrathecal injection of local anesthetics into the subarachnoid space, producing a rapid-onset, dense sensory and motor block. It is particularly suited for operations involving the lower abdomen, pelvis, and lower extremities. When combined with GA, spinal anesthesia enables substantial dose reduction of inhaled anesthetics and opioids, attenuates the neuroendocrine stress response, and improves hemodynamic stability [25].

Epidural anesthesia, achieved through catheter placement in the epidural space, allows continuous or intermittent administration of local anesthetics, providing prolonged and titratable analgesia. It is widely employed in thoracic, abdominal, and obstetric surgery, particularly for postoperative pain management.

The combined spinal-epidural technique merges the rapid onset of spinal anesthesia with the extended control of an epidural catheter, making it especially useful for prolonged or staged surgical procedures [26].

Peripheral nerve blocks deliver highly localized analgesia with minimal systemic effects. For upper extremity surgery, interscalene, supraclavicular, infraclavicular, and axillary blocks are commonly used to manage pain in procedures ranging from shoulder to hand, while preserving hemodynamic stability and reducing opioid use.

Lower extremity blocks, including femoral, adductor canal, sciatic, and interspace between popliteal artery and capsule of the knee (iPACK) blocks, play a key role in total joint arthroplasty and orthopedic trauma surgery. Motor-sparing approaches, such as the adductor canal block, are particularly advantageous in facilitating early ambulation and functional recovery after total knee replacement.

Truncal blocks—including transversus abdominis plane (TAP), QL, ESP, and paravertebral blocks (PVBs)—are highly effective for controlling both somatic and visceral pain during abdominal and thoracic operations [27,28]. Among these, ESP and serratus anterior plane blocks are increasingly preferred in patients with coagulopathies as safer alternatives to epidural anesthesia [29].

Local anesthetic infiltration at the surgical site remains a simple

Table 1. Regional anesthetic techniques applicable in surgical contexts

	Regional anesthetic techniques
Neuraxial anesthesia	Spinal anesthesia
	Epidural anesthesia
	Combined spinal-epidural
	Caudal epidural block
Paraspinal blocks	Erector spinae plane block
	Cervical
	Thoracic
	Lumbar
	Paravertebral block (thoracic, lumbar)
	Costotransverse foramen block
	Intertransverse process block
Upper extremity-brachial plexus blocks	Thoracolumbar interfascial plane block
	Interscalene block
	Supraclavicular block
	Infraclavicular block
Upper extremity-terminal nerve blocks	Axillary block
	Median nerve block
	Ulnar nerve block
	Radial nerve block
	Musculocutaneous nerve block
	Medial antebrachial cutaneous nerve block
	Lateral antebrachial cutaneous nerve block
Lower extremity-lumbar plexus blocks	Suprascapular block
	Dorsal scapular nerve block
	Lumbar plexus block
	Psoas compartment block
Lower extremity-lumbar plexus-related	Posterior lumbar plexus block
	Femoral nerve block
	Adductor canal block
	Obturator nerve block
	Lateral femoral cutaneous nerve block
	Genitofemoral nerve block
	Ilioinguinal/iliohypogastric nerve block
	Sciatic nerve block (subgluteal, infragluteal, transgluteal)
	Popliteal sciatic nerve block (lateral, posterior)
	Posterior femoral cutaneous nerve block
Lower extremity-distal leg and ankle	Saphenous nerve block
	Ankle block

(Continued on the next page)

Table 1. Continued

	Regional anesthetic techniques
	Tibial nerve
	Deep peroneal nerve
	Superficial peroneal nerve
	Sural nerve
	Saphenous nerve
Truncal	TAP blocks
	Lateral TAP block
	Posterior TAP block
	Subcostal TAP block
	Dual TAP block
	Rectus sheath block
	Ilioinguinal/iliohypogastric block
	QL blocks
	QL1 (lateral)
	QL2 (posterior)
	QL3 (transmuscular)
	QL4 (intramuscular variant)
	Transversalis fascia plane block
Thoracic–interfascial plane blocks	PECS I block (pectoralis and serratus plane)
	PECS II block
	Serratus anterior plane block
	Clavipectoral fascial plane block
	Intercostal nerve block
	Transversus thoracic plane block
Head and neck–cervical plexus	Cervical plexus block
	Superficial
	Intermediate
	Deep
Head and neck	Scalp nerve block
	Supraorbital nerve block
	Supratrochlear nerve block
	Zygomaticotemporal nerve block
	Greater occipital nerve block
	Lesser occipital nerve block
	Auriculotemporal nerve block
Airway	Glossopharyngeal nerve block
	Superior laryngeal nerve block
	Recurrent laryngeal nerve block
	Translaryngeal block
Distal digital and penile blocks	Digital nerve block (4–point, 2–point)
	Penile block (dorsal nerve, ring block)
Intravenous regional anesthesia (bier block)	–
Wound infiltration	–

TAP, transverse abdominis plane; QL, quadratus lumborum.

yet effective technique, particularly in minimally invasive operations or as part of multimodal analgesia. Field blocks such as rectus sheath and ilioinguinal/iliohypogastric blocks are frequently employed in inguinal hernia repair and lower abdominal surgery.

The widespread adoption of ultrasound guidance has revolutionized RA practice by enabling real-time visualization of anatomical structures, thereby increasing accuracy and reducing complications such as vascular puncture or nerve injury.

Continuous catheter-based RA techniques extend analgesic coverage into the postoperative period, allowing titration of doses for sustained pain control. Furthermore, the use of sustained-release local anesthetic delivery systems and adjuvants, including dexamethasone, clonidine, and dexmedetomidine, can prolong block duration and enhance analgesic efficacy [5,30].

The choice of RA technique should be individualized based on surgical site, patient comorbidities, coagulation profile, and recovery goals. When optimally implemented, RA techniques improve pain control, enhance patient satisfaction, reduce opioid-related adverse effects, and accelerate functional recovery [21,22].

Surgical applications

RA plays a pivotal role in optimizing perioperative analgesia across a broad range of surgical disciplines. In abdominal surgery, RA techniques have become integral to opioid-sparing multimodal strategies [23]. The TAP block, which targets the intercostal nerves (T6–L1) within the fascial plane between the internal oblique and transversus abdominis muscles, is widely used in both open and laparoscopic procedures. It provides effective somatic analgesia of the anterior abdominal wall, thereby reducing systemic opioid use, postoperative nausea, and ileus [24]. The QL block, a deeper posterior fascial plane block, offers broader analgesic spread into the thoracolumbar fascia and paravertebral space, potentially covering visceral pain pathways. Its application in colorectal, urological, and gynecological surgery has been associated with improved pain scores and enhanced recovery outcomes [31]. For major open abdominal procedures, thoracic or lumbar epidural analgesia remains the gold standard, providing both somatic and visceral pain relief. Epidural anesthesia also improves bowel motility, reduces postoperative ileus, and decreases pulmonary complications such as atelectasis and pneumonia, particularly in patients undergoing bowel resection or hepatobiliary surgery [32].

In thoracic surgery, effective analgesia is essential due to the high risk of respiratory complications and the severity of post-thoracotomy pain [22,29]. Even minimally invasive approaches such as video-assisted thoracoscopic surgery can cause significant dis-

comfort from intercostal nerve trauma. Thoracic epidural analgesia, which produces dense, multisegmental sympathetic and sensory blockade, has long been the standard for open thoracotomies and is associated with decreased pulmonary morbidity and lower rates of postoperative respiratory failure [33]. However, newer fascial plane blocks such as the PVB and erector spinae plane block (ESPB) provide safer alternatives with comparable efficacy. These techniques can be administered unilaterally, produce less hypotension, and are safer in patients requiring anticoagulation. Randomized trials have demonstrated that PVB and ESPB reduce opioid use, facilitate early mobilization, and lower the incidence of chronic post-thoracotomy pain syndrome [34,35].

RA is equally indispensable in orthopedic surgery, where functional recovery and early rehabilitation are critical to long-term outcomes [11]. Peripheral nerve blocks for major joint procedures provide targeted analgesia while enabling motor-sparing approaches. For instance, femoral and adductor canal blocks are frequently used in total knee arthroplasty (TKA), with the latter preferred for preserving quadriceps strength while maintaining analgesia of the anteromedial knee. The iPACK block, which targets posterior capsule innervation without affecting motor function, further complements analgesic coverage in TKA [36]. Continuous catheter techniques are particularly beneficial in major joint surgery by delivering titratable, extended analgesia, thereby supporting early ambulation, reducing systemic opioid needs, and lowering the risk of chronic stiffness [37,38]. In upper limb procedures, interscalene and supraclavicular brachial plexus blocks provide profound analgesia for shoulder and arm surgery, facilitating same-day discharge and shorter hospital stays.

In pediatric populations, the use of RA is expanding due to its effectiveness in minimizing perioperative opioid exposure, reducing emergence delirium, and improving overall comfort [39]. Caudal epidural blocks remain one of the most frequently employed techniques for subumbilical procedures in infants and children [40]. Ultrasound-guided TAP and QL blocks have been safely adapted to pediatric practice, demonstrating efficacy in laparoscopic appendectomies, herniorrhaphies, and urological operations. In thoracic and cardiac surgery, fascial plane blocks such as parasternal and ESP blocks serve as alternatives when neuraxial techniques are contraindicated by anticoagulation or anatomical limitations. Additionally, RA in children has been associated with fewer postoperative behavioral disturbances, shorter post-anesthesia care unit stays, and reduced incidence of postoperative nausea and vomiting [39,41].

The use of RA should be tailored to the surgical procedure, patient comorbidities, and recovery objectives. By limiting systemic opioid exposure and providing targeted pain relief, RA facilitates

early mobilization, reduces perioperative complications, and supports improved long-term functional outcomes. As surgical techniques and patient expectations evolve, the integration of RA into individualized perioperative care pathways continues to be a cornerstone of high-quality surgical management.

Role in ERAS protocols

The ERAS program is a multimodal, evidence-based perioperative pathway designed to reduce surgical stress, accelerate recovery, and shorten hospital stays [3,42,43]. Regional anesthesia is central to ERAS protocols because of its ability to attenuate neuroendocrine responses, provide superior analgesia, and enable early mobilization.

Effective pain management is a cornerstone of ERAS, and the use of regional techniques—such as neuraxial blocks, fascial plane blocks, and peripheral nerve blocks—substantially reduces reliance on systemic opioids [42]. This opioid-sparing effect decreases the incidence of nausea, vomiting, ileus, sedation, urinary retention, and respiratory depression, all of which can delay recovery.

In abdominal surgery, thoracic epidural analgesia or TAP/QL blocks are frequently incorporated into ERAS protocols to facilitate earlier ambulation and faster resumption of enteral nutrition [23]. In orthopedic procedures, adductor canal and iPACK blocks are emphasized for their ability to preserve motor strength and optimize postoperative physiotherapy [21]. Pediatric ERAS adaptations also increasingly incorporate regional techniques to improve comfort, reduce anxiety, and minimize opioid exposure [39].

Clinical evidence demonstrates that integrating RA into ERAS reduces postoperative pain scores, opioid use, complications, and hospital length of stay. Furthermore, the physiological benefits of RA, including improved pulmonary function and modulation of inflammatory responses, contribute to better surgical outcomes [3,20,43].

Successful implementation of RA within ERAS requires close interdisciplinary collaboration, careful patient selection, adherence to standardized protocols, and investment in both training and equipment. As ERAS protocols evolve, RA remains central to advancing perioperative care by aligning safety, recovery optimization, and patient-centered outcomes.

Safety and limitations

Although RA provides substantial benefits when combined with GA, its application must be carefully weighed against associated

risks and procedural limitations [44]. Table 2 summarizes potential complications following RA. The most serious complications include local anesthetic systemic toxicity (LAST), bleeding, infection, nerve injury, and inadvertent dural puncture. LAST, although rare, with estimates around 0.03% or 0.27 episodes per 1,000 nerve blocks, is potentially fatal—particularly in high-volume blocks or accidental intravascular injection—and necessitates early recognition and immediate treatment with lipid emulsion therapy [44]. The incidence of neurological complications after regional anesthesia is reported to be between 1/1,000 and 1/1,000,000. Bleeding risk is especially pertinent in neuraxial and deep peripheral blocks, particularly in patients on antithrombotic therapy. The incidence of epidural or spinal hematoma has been

reported to be approximately 1:150,000 for epidural blocks and 1:220,000 for spinal anesthetics. To mitigate these risks, strict adherence to anticoagulation management guidelines, such as those established by the American Society of Regional Anesthesia and Pain Medicine, is mandatory [45]. Nerve injury, though uncommon, may result from direct mechanical trauma, intraneural injection, or ischemia, and can range from transient paresthesia to long-term sensorimotor deficits.

The use of ultrasound guidance and refined injection techniques plays a critical role in minimizing neural complications [21]. However, successful execution of RA requires highly trained personnel, specialized equipment such as ultrasound machines and nerve stimulators, and institutional infrastructure to support perioperative analgesia services. Variability in provider expertise and limited resource availability, particularly in low-resource settings, remain significant barriers to widespread adoption.

In addition to procedural risks, clinical challenges such as rebound hyperalgesia and limited block duration must be addressed. Single-shot RA typically provides analgesia for 12–24 hours, after which patients may experience rebound pain. This limitation can be mitigated by incorporating preemptive multimodal analgesia, sustained-release local anesthetic formulations, adjuvants such as dexamethasone or clonidine, or continuous catheter-based techniques [5,30,46]. Not all patients are suitable candidates for RA. Contraindications include patient refusal, local infection, coagulopathy, hypersensitivity to local anesthetics, and anatomical abnormalities that compromise safe block placement. Careful preoperative assessment and interdisciplinary consultation are essential to identify appropriate candidates. In addition, standardized documentation—including informed consent, block details (site, technique, drug, and dose), and vigilant post-procedural monitoring—is necessary to ensure quality, detect complications early, and manage delayed adverse events [11]. In summary, RA is a powerful component of multimodal analgesia, but its safety and efficacy depend on meticulous planning, clinical expertise, and ongoing monitoring. Broader adoption will require overcoming current barriers through enhanced clinician education, standardized institutional protocols, and the integration of enabling technologies.

Future perspectives

The rapidly evolving field of perioperative medicine offers significant opportunities to expand and refine the role of RA in combination with GA. Anticipated advancements encompass pharmacological innovation, digital technologies, personalized medicine, educational reform, and health system integration, all directed to-

Table 2. Possible complications of regional anesthesia

Possible complications of regional anesthesia
Nerve injury (transient or permanent)
Spinal cord injury
Radiculitis and nerve root irritation
Arachnoiditis
Cauda equina syndrome
Conus medullaris syndrome
Spinal or epidural hematoma
Local bleeding or bruising at puncture site
Epidural abscess
Meningitis
Local infection at needle or catheter site
Post-dural puncture headache
Hypotension
Bradycardia
Arrhythmias
Respiratory depression
LAST
Seizures due to LAST
Cardiac arrest due to LAST
Allergic reactions to local anesthetics or preservatives
Failed or incomplete block
Unintentional high block
Needle or catheter breakage
Back pain at injection site
Fibrosis or scarring of neuraxis
Meningeal deformities
Pseudomeningocele
Syringomyelia
Polyradiculopathy
Block failure
Pseudoaneurysm
Vascular puncture

LAST, local anesthetic systemic toxicity.

ward improving patient outcomes, enhancing safety, and optimizing resource utilization.

Recent developments in long-acting local anesthetic formulations, such as liposomal bupivacaine and polymer-based drug carriers, have the potential to extend the duration of single-injection RA while minimizing systemic toxicity [5,47]. Ongoing research is also investigating nanoparticle-based platforms, pH-responsive release mechanisms, and perineural adjuvants, all designed to increase selectivity, improve safety, and enhance the efficacy of local anesthetic administration [30,46].

The integration of artificial intelligence, machine learning, and predictive analytics holds promise for developing personalized RA strategies. Algorithms that incorporate patient-specific variables, including demographics, comorbidities, surgical characteristics, and pain sensitivity, may support tailored decisions on block selection, anesthetic dosing, and catheter management, ultimately optimizing analgesia and recovery trajectories.

Emerging technologies such as perineural pressure sensors, ultrasound elastography, and sensor-equipped needles are expected to improve the precision and safety of RA by providing real-time feedback during block placement. Furthermore, embedding clinical decision-support tools within anesthesia information management systems could enhance consistency in RA delivery, reduce errors, and promote adherence to evidence-based best practices.

Discussion

In addition to its well-documented benefits for perioperative pain management, recent evidence has linked RA with improved neurocognitive outcomes, particularly in older patients. The pathogenesis of postoperative cognitive dysfunction is multifactorial, involving mechanisms such as hypotension-induced cerebral ischemia, systemic inflammation, and neurotoxicity from anesthetic agents [48,49]. Epidural analgesia may provide a protective effect by attenuating inflammatory responses and reducing intraoperative hemodynamic fluctuations [50]. However, findings from meta-analyses remain mixed, suggesting that RA should be regarded as one component of a broader neuroprotective strategy rather than as a stand-alone intervention. Complementary measures—including strict intraoperative blood pressure control and multimodal neuroprotective protocols—are equally important.

The immunomodulatory effects of RA are another area of growing interest, particularly in oncological surgery. By blunting the surgical stress response and preserving NK cell activity, RA may influence tumor recurrence and metastasis [9,10]. Although causal relationships are still under investigation, retrospective analyses have suggested improved recurrence-free survival among

patients receiving RA during cancer resection procedures.

Pharmacological innovations continue to expand the clinical utility of RA. Long-acting local anesthetic formulations such as liposomal bupivacaine extend the duration of single-shot blocks, while adjuvants including dexamethasone, clonidine, and dexmedetomidine enhance both block quality and duration [30,46]. These adjuncts are increasingly incorporated into practice to optimize analgesia and tailor regimens to patient needs.

RA also demonstrates particular value in high-risk populations. For patients with significant cardiovascular or pulmonary comorbidities, RA reduces the requirement for systemic medications and mitigates sympathetic activation. In patients with chronic kidney disease, RA may help avoid nephrotoxic systemic analgesics and maintain renal perfusion by minimizing opioid use and reducing hypotensive episodes.

Ultimately, the success of RA-GA integration relies not only on technical proficiency but also on comprehensive interdisciplinary planning, thoughtful patient selection, and adherence to standardized protocols. As the evidence base continues to expand, anesthesiologists are uniquely positioned to lead multimodal strategies that integrate RA to improve both short- and long-term surgical outcomes.

Conclusion

The integration of RA with GA provides a robust multimodal approach to address the complex and multifactorial nature of postoperative pain. Supported by a growing body of clinical evidence and closely aligned with the ERAS paradigm, this strategy should be routinely considered across diverse surgical populations. Widespread adoption, however, will depend on continued research, equitable dissemination, and comprehensive education to ensure safe and effective implementation. Importantly, the long-term benefits of RA-GA integration extend beyond perioperative analgesia. Reduced chronic pain, enhanced functional independence, improved immune recovery, and even favorable oncological outcomes underscore the need to prioritize perioperative pain control as an essential component of comprehensive surgical care.

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Conceptualization: MKK, OHL, HK. Methodology/formal analysis/validation: MKK, HK. Writing—original draft: MKK,

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