Intraoperative Management for Enhanced Recovery After Gynecologic Surgery

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Abstract: Enhanced recovery after surgery (ERAS) protocols have revolutionized perioperative care, aiming to reduce surgical stress and expedite recovery. In gynecologic surgery, anesthesiologists play a pivotal role in implementing intraoperative strategies that align with ERAS principles. This manuscript delineates evidence-based intraoperative anesthetic management techniques tailored for gynecologic procedures within an ERAS framework, including multimodal analgesia, optimal fluid management, maintenance of normothermia, and lung protective ventilation (Figure 1). The integration of these strategies has demonstrated improvements in patient outcomes, including reduced hospital stays, decreased opioid consumption, and enhanced patient satisfaction.

Key Words: ERAS and anesthesiology, intraoperative opioids, opioid sparing, intraoperative anesthesia technique, multimodal analgesia

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Gynecologic surgeries encompass a wide range of procedures, from minimally invasive laparoscopies to extensive oncologic resections. Traditionally, perioperative care in these surgeries involved prolonged fasting, liberal fluid administration, and reliance on opioids for pain control, often leading to extended recovery periods and increased morbidity. The advent of ERAS protocols (Figure 1) has challenged these conventions by promoting evidence-based practices that mitigate surgical stress, decrease opioid consumption, and foster rapid recovery.[1–3,4] Shifts in practice have included a reduced reliance on epidural analgesia in favor of truncal blocks and local infiltration techniques for multimodal analgesia. For oncology patients, faster recovery is especially important as it leads to earlier return to intended oncologic treatment (RIOT) with meaningful impacts on cancer outcomes.[5]

Anesthesiologists are integral to the successful implementation of ERAS protocols, particularly during the intraoperative phase. Their expertise in anesthesia management directly influences postoperative outcomes. This manuscript explores the intraoperative anesthetic considerations and interventions that align with ERAS principles in gynecologic surgery.[6]

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PREOPERATIVE CONSIDERATIONS

While the focus of this manuscript is on intraoperative management, it is essential to acknowledge the interplay between preoperative and intraoperative phases. Preoperative optimization encompasses several key elements, including patient education, frailty and nutritional assessment, prehabilitation, skin preparation, and preoperative administration of carbohydrate solutions in patients without concern for delayed gastric emptying.[7–11] This lays the critical groundwork for successful intraoperative anesthetic management and subsequent postoperative recovery within an ERAS protocol.

SURGICAL TECHNIQUE

Minimally Invasive Surgery (MIS)

Minimally invasive surgery is a key tenet of ERAS.[12,13] It is recommended for appropriate patients when long-term oncologic outcomes are similar to open surgery and where expertise and resources are available. The adoption of minimally invasive laparoscopy and robotic surgery in gynecology has led to substantial improvements in patient outcomes by decreasing intraoperative blood loss, length of stay, analgesic requirements, return of bowel function, length of hospitalization, and return to normal daily activities. Laparoscopic surgery has been associated with a decrease in the cortisol stress response to surgery compared with open procedures with associated inflammatory and immunomodulatory effects.[14] Retrospective comparative studies suggest that ERAS implementation in minimally invasive surgery is associated with improvements in length of stay and cost.[15] In addition, MIS has been linked to decreased intraoperative and postoperative morphine equivalents, decreased cost, and increased patient satisfaction. Patients undergoing minimally invasive surgery on an ERAS pathway report faster recovery, less pain, less interference with walking, and less fatigue compared with patients undergoing open surgery on an ERAS pathway. However, it is important to note that in early cervical cancer, patients undergoing MIS have shown higher recurrence rates and worse survival compared with open surgery.[16] Therefore, the benefits of MIS need to be carefully weighed against oncologic outcomes.

Avoiding Unnecessarily Steep Trendelenburg Positioning

The steep Trendelenburg position, commonly used during laparoscopic and robotic gynecologic oncology surgery to optimize surgical exposure in the pelvic region, is not without physiological consequences, particularly concerning respiratory function.[17] This head-down tilt, especially when combined with pneumoperitoneum, can significantly reduce functional residual capacity (FRC) and overall lung volume by promoting the cephalad

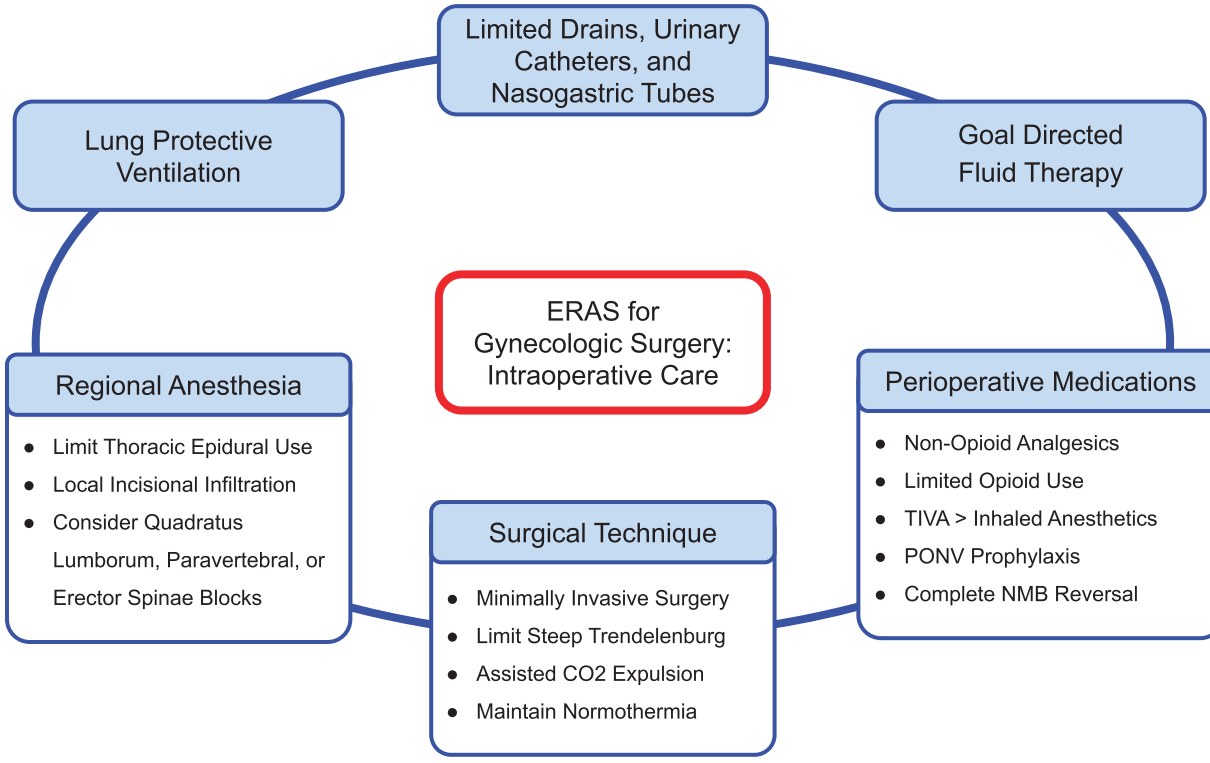

FIGURE 1. ERAS for gynecologic surgery: intraoperative care. full color online

displacement of abdominal contents, which in turn compresses the diaphragm. This compression leads to a decrease in respiratory compliance and an increase in airway resistance, creating a predisposition for atelectasis, especially in the dependent dorsal lung regions. The mismatching of ventilation and perfusion ratios can subsequently increase the risk of postoperative pulmonary complications. Obese patients are particularly vulnerable to these effects, often experiencing a larger reduction in lung gas volume and respiratory compliance compared with those with a normal body mass index, and they may exhibit higher peak inspiratory airway pressures and driving pressures during steep Trendelenburg with pneumoperitoneum. Furthermore, the Trendelenburg position is known to cause a significant increase in intraocular pressure (IOP), which can elevate the risk of postoperative vision loss and other ocular complications.[18,19] Steeper degrees of Trendelenburg and prolonged durations in this position correlate with greater increases in IOP. Blinded studies of steep versus moderate Trendelenburg in pelvic robotic surgery have found that 28 degrees is sufficient for most gynecologic surgical procedures.[20,21] Therefore, while sometimes necessary for surgical access, employing the least steep Trendelenburg angle for the shortest duration possible, while still maintaining adequate surgical field visibility, should be a consideration in ERAS protocols for gynecologic oncology surgery.

Assisted Expulsion of CO2 to Reduce Postlaparoscopic Shoulder Pain

Pulmonary recruitment maneuvers at the end of laparoscopic surgery can play a valuable role in assisting with the expulsion of residual carbon dioxide (CO2) to reduce postlaparoscopic shoulder pain (PLSP).[22] PLSP is a common complaint following laparoscopic surgery, attributed to diaphragmatic irritation from retained CO2. Recruitment maneuvers involving transient increases in airway pressure through manual or ventilator-driven lung inflations, help to re-expand collapsed alveoli and simultaneously increase intrathoracic and intraperitoneal pressure, thereby facilitating the evacuation of residual CO2 from the abdominal cavity through the surgical ports. A meta-analysis has confirmed that pulmonary recruitment maneuvers significantly decrease postlaparoscopic shoulder pain at various postoperative time points.[23] A typical technique involves performing 1 or 2 manual inflations to a peak pressure of around 30 to 40 cmH2O, holding for a few seconds, with the operative ports open at the end of the procedure while the patient is still in the Trendelenburg position. This active removal of CO2 has been shown to be more effective in reducing PLSP compared with passive deflation alone.[23] While safe, pulmonary recruitment maneuvers should be used judiciously, avoiding high pressures in patients with hemodynamic instability or other contraindications, to minimize the risk of barotrauma or hemodynamic compromise.

Maintenance of Normothermia

Maintaining normothermia is a crucial element of ERAS protocols in gynecologic surgery, as it has significant implications for patient outcomes. Inadvertent perioperative hypothermia has been linked to an increased risk of surgical site infections and cardiac events. Various methods, including forced air warming devices, underbody warming mattresses, and warmed intravenous fluid administration, can be used to avoid this. Evidence from a randomized

clinical trial involving patients undergoing major abdominal surgery demonstrated that maintaining normothermia perioperatively, through additional warming before and after surgery, reduced the rate of surgical site infections by over half and shortened hospital stays.[24] Intraoperative hypothermia has also been linked to an increased risk of cardiac events.[25] This finding aligns with the Centers for Disease Control and Prevention (CDC) endorsement of perioperative normothermia as a category 1A recommendation for preventing surgical site infections.

DRAINS, URINARY CATHETERS, AND NASOGASTRIC TUBES

A critical aspect of ERAS pathways involves the judicious use of postoperative adjuncts such as urinary catheters, surgical drains, and nasogastric tubes to facilitate early mobilization and reduce the potential for complications.

Urinary Catheters

The contemporary approach to urinary drainage in gynecologic surgery emphasizes early removal of indwelling bladder catheters (IBCs). While historical practices often involved prolonged catheterization to prevent urinary retention, current evidence indicates that extended use is associated with a heightened risk of urinary tract infections, postoperative urinary retention, and pressure injuries, which can impede patient mobilization and recovery.[26] For patients undergoing minimally invasive surgical (MIS) procedures, same-day removal of the IBC is increasingly supported by the evidence, with studies demonstrating low rates of persistent urinary retention that often resolve spontaneously. In the context of laparotomy, the recommendation is for removal of the IBC by postoperative day one, provided there are no specific clinical factors warranting continued drainage. Notably, even following radical hysterectomy, early removal of the urinary catheter (within the first few postoperative days) has not been shown to increase the incidence of voiding dysfunction or other genitourinary complications.[27] In instances of postoperative urinary retention, the use of intermittent self-catheterization is preferred over the reinsertion of an indwelling catheter.[28] Patients in critical care settings requiring meticulous monitoring of urine output may constitute an exception to this general principle.

Surgical Drains

The routine placement of surgical drains, including subcutaneous and peritoneal drains, for the primary prevention of surgical site infections (SSIs) is not supported by current high-quality evidence in gynecologic surgery. Research has demonstrated that bacterial colonization of drains can occur rapidly, potentially providing a pathway for the introduction of bacteria into the surgical site and increasing the risk of infection.[29] While certain SSI reduction bundles have included the use of subcutaneous drains in specific patient populations, such as obese individuals, these bundles also encompassed other interventions with stronger evidence for SSI prevention.[11] Consequently, there is insufficient evidence to recommend the routine inclusion of subcutaneous or peritoneal drains as a component of SSI prevention strategies, and their indiscriminate use may even be detrimental. The decision to utilize surgical drains should therefore be highly selective and based on the specific surgical procedure and a clear clinical indication in an individual patient.

Nasogastric Tubes

Current evidence advises against the routine use of nasogastric (NG) tubes following elective abdominal surgery in gynecologic oncology. Studies have indicated that routine NG tube placement can increase the risk of postoperative pneumonia without a concomitant reduction in the rates of wound dehiscence or intestinal leaks. Further, leaving in NG tubes can delay the start of postoperative oral intake, which has been shown to negatively impact the return of bowel function.[30] The decision to employ an NG tube should be carefully considered and reserved for specific clinical scenarios where there is a clear indication for gastric decompression.

Routine preoperative mechanical bowel preparation (MBP) is also generally discouraged before minimally invasive and open gynecologic surgeries. Data from randomized controlled trials in minimally invasive gynecologic surgery conclusively show that MBP is not associated with improved intraoperative visualization, ease of bowel handling, or procedure performance.[31] MBP is also ineffective in improving postoperative complications and is potentially harmful as it can contribute to preoperative dehydration, decreased exercise capacity, and electrolyte abnormalities.[32]

REGIONAL ANESTHESIA

Regional anesthetic techniques (Figs. 1, 2) are a cornerstone of enhanced recovery after surgery (ERAS) pathways, playing a crucial role in reducing the stress

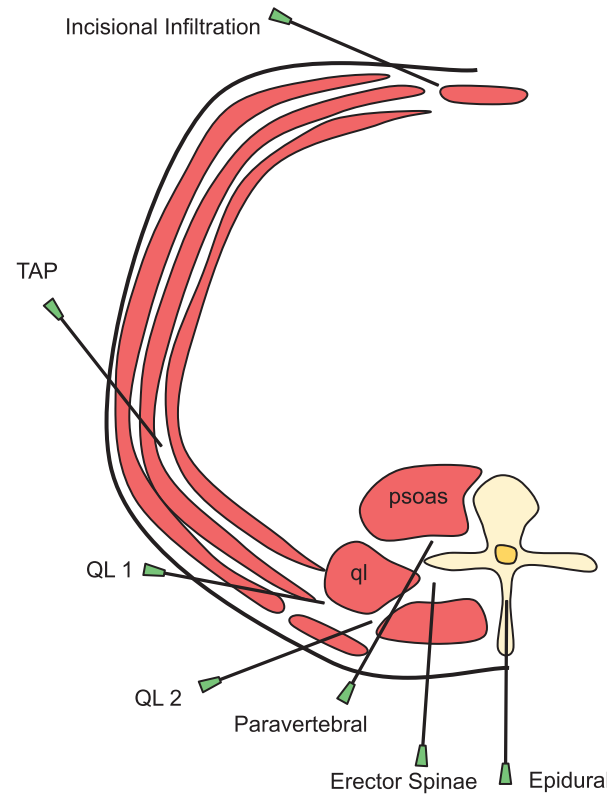

FIGURE 2. Regional anesthesia injection locations. full color online

response, decreasing the need for opioid analgesics, and ultimately improving postoperative outcomes.[33] By providing targeted pain relief, these techniques contribute significantly to the goal of minimizing opioid consumption, which is essential for reducing opioid-related side effects and the risk of dependence.[1,34]

Thoracic Epidural Analgesia

Thoracic epidural analgesia (TEA) has been shown to be effective in controlling postsurgical pain and reducing opioid requirements after major abdominal surgery and may speed recovery of GI function. However, TEA is associated with several potential downsides and complications, including a significant failure rate (up to 30%), intraoperative hypotension often requiring vasopressors and fluid boluses (interfering with euvolemia), and hindrance of early mobilization.[35] Patients with epidurals may still require patient-controlled analgesia (PCA), and other potential untoward effects include pruritus, postoperative nausea and vomiting (PONV), prolonged block, and urinary retention.[36] Recent evidence suggests that in gynecologic oncology surgery within ERAS protocols, the risks of TEA may outweigh its benefits.

Local Incisional Infiltration

Given the potential for complications associated with TEA, local incisional infiltration with local anesthetic is strongly recommended as a key component of multimodal analgesia in gynecologic surgery. It is a simple and safe technique that can be effective when used with multimodal oral pain regimens. Local infiltration has minimal systemic side effects and can offer sustained pain relief, especially with long-acting local anesthetics like liposomal bupivacaine, potentially benefiting patients undergoing complex cytoreduction.[37]

TAP Blocks

The evidence supporting the analgesic effectiveness of TAP blocks after hysterectomy is mixed. While some investigations have shown a reduction in postoperative opioid consumption in the early postoperative period, others have failed to show significant improvements in pain control compared with placebo or wound infiltration.[38–41] Meta-analyses have shown only modest reductions in postoperative pain with TAP blocks.[42] Furthermore, in open gynecologic surgery, some studies have found no significant difference in opioid consumption or length of stay with TAP blocks.[43] Direct comparisons have not consistently demonstrated a clinical benefit of TAP over incisional injection.

Paravertebral Blocks and Erector Spinae Plane (ESP) Blocks

Thoracic paravertebral block has demonstrated analgesic effectiveness after major gynecologic cancer surgery. Studies show that bilateral thoracic paravertebral blocks can lead to significant reductions in both opioid requirements and pain scores during early and late postoperative periods.[44] The erector spinae plane (ESP) block is a newer inter-fascial technique where local anesthetic is injected near the erector spinae muscles to achieve a unilateral somatic and visceral sensory block from the T1 to L3 levels. Due to the more superficial approach, ESP blocks have a lower risk of complications than paravertebral blocks.[45] ESP blocks have also been shown to significantly improve postoperative pain scores after gynecologic surgical procedures, but the evidence base in this setting is still developing.[46] In cases where epidural analgesia is contraindicated, refused, or fails, paravertebral and ESP blocks can serve as effective analgesia adjuncts.

Quadratus lumborum (QL) blocks

Quadratus lumborum (QL) blocks are a newer truncal nerve block technique shown to be effective in managing postoperative pain after gynecologic surgical procedures.[47] Studies report significant decreases in pain scores and reduced opioid or other analgesic consumption, as well as lengthened time to first analgesic with the use of QL blocks. Some evidence suggests that QL blocks may be more effective at managing postoperative pain and have a lower risk for systemic toxicity compared with TAP blocks. The posterior QL block may be preferable for extensive lower abdominal procedures due to its predictable spread and broader analgesic effect.

In summary, while regional anesthesia is vital for reducing opioid consumption in ERAS pathways, local incisional infiltration with local anesthetic is strongly recommended as a key component of multimodal analgesia due to its efficacy and minimal side effects. TAP blocks and QL blocks can also be considered as part of a multimodal approach to pain management, with QL blocks showing promising results in recent studies. Paravertebral or erector spinae blocks offer another effective option with increasing evidence to support their use. TEA should be approached with caution in the context of gynecologic ERAS due to its potential for complications that could hinder recovery. The choice of regional anesthesia technique should be tailored to the individual patient and the surgical procedure, considering the available evidence and potential risks and benefits.

LUNG PROTECTIVE VENTILATION

Lung protective ventilation in gynecologic surgery is essential, especially given the frequent use of pneumoperitoneum and Trendelenburg positioning, to decrease the likelihood of postoperative pulmonary complications. A cornerstone of this approach is the use of low tidal volumes, ideally in the range of 6 to 8 mL/kg of ideal body weight, which has been shown to reduce pulmonary complications in open abdominal surgery by minimizing alveolar overdistension and ventilator-induced lung injury.[48] Furthermore, positive end-expiratory pressure (PEEP) plays a vital role in preventing atelectasis by maintaining alveolar patency and improving oxygenation. Observational studies and randomized controlled trials into optimal PEEP levels during abdominal laparoscopic surgery with Trendelenburg positioning indicate that zero end-expiratory pressure should be avoided, and moderate PEEP within the 4 to 8 cmH2O range appears to yield better outcomes compared with higher PEEP levels exceeding 10 cmH2O.[18] It is worth noting that the ideal PEEP setting might vary among individual patients, and some evidence points towards the potential benefits of individualized PEEP titration guided by advanced monitoring techniques. In addition to low tidal volumes and PEEP, pulmonary recruitment maneuvers (PRMs), which involve temporarily increasing airway pressure to reopen collapsed alveoli, are frequently considered as part of a lung protective ventilation strategy. While PRMs have demonstrated the ability to improve intraoperative arterial oxygenation and the distribution of ventilation, the most effective PRM technique and the optimal frequency of their application are still under

investigation. Moreover, PRMs carry potential risks, including barotrauma and hypotension.

FLUID MANAGEMENT

Optimal perioperative fluid management is a critical component of ERAS in gynecologic procedures, as both inadequate and excessive intravenous fluid administration can lead to adverse outcomes. Goal-directed fluid therapy (GDFT) is a technique recommended for managing hemodynamics, utilizing fluids and inotropes to improve tissue perfusion and oxygenation, especially in high-risk surgical patients. The routine use of specific clinical GDFT guidelines or algorithms employing physiological measurements of blood flow, fluid responsiveness, and organ perfusion is gaining recognition. GDFT, often facilitated by minimally invasive hemodynamic monitoring to detect flow-related parameters and dynamic parameters of fluid responsiveness, allows for the titration of intravenous fluids and/or inotropic therapy to optimize end-organ tissue perfusion. Evidence suggests that perioperative goal-directed fluid therapy reduces length of stay and complications in high-risk patients undergoing abdominal surgery.

Employing dynamic monitoring tools, such as stroke volume variation (SVV), pulse pressure variation, or systolic pressure variation, is essential in guiding fluid administration. Fluid optimization guided by SVV has been associated with hemodynamic stability and decreased lactate levels, as well as reduced postoperative organ complications. Studies have shown that the implementation of ERAS protocols, including GDFT guided by tools like the Masimo pleth variability index, is associated with a substantial decrease in the volume of intravenous fluids administered. It is important to achieve euvolemia, avoiding both hypovolemia, which can lead to complications like acute kidney injury and surgical site infections, and hypervolemia, associated with delayed return of bowel function, postoperative ileus, and increased length of stay.[49]

When considering intravenous fluid therapy in the perioperative setting, balanced crystalloid solutions have multiple benefits over 0.9% saline. A systematic review and meta-analysis of randomized controlled trials examining intraoperative fluid use found that balanced crystalloids probably lead to a higher postoperative serum pH and lower chloride levels compared with saline.[50] However, this review also noted that the effect of balanced crystalloids on postoperative mortality and the need for renal replacement therapy remains uncertain.

The SMART trial, a pragmatic cluster-randomized trial conducted in critically ill adults, provided further evidence in this area.[51] This study found that the use of balanced crystalloids resulted in a lower rate of a major adverse kidney event within 30 days, a composite outcome of death from any cause, new renal-replacement therapy, or persistent renal dysfunction, compared with the use of saline. The trial suggested that balanced crystalloids rather than saline might prevent adverse kidney events in many critically ill patients.

PREOPERATIVE AND INTRAOPERATIVE MEDICATIONS

Nonopioid Analgesics

Nonopioid analgesics play a crucial role in effective pain management within enhanced recovery after surgery (ERAS) protocols for gynecologic procedures. The intraoperative administration of these agents, as part of a multimodal regimen, aims to enhance analgesia and reduce the consumption of opioids, thereby minimizing opioid-related side effects. Acetaminophen and nonsteroidal anti-inflammatory drugs (NSAIDs) are commonly used nonopioid analgesics with different mechanisms of action. Their combination has been shown to be superior to using either drug alone for acute postoperative pain.[52] Routine scheduled postoperative administration of oral acetaminophen and NSAIDs is advised unless contraindicated.

Gabapentinoids, such as gabapentin and pregabalin, are other nonopioid agents that can be included in a multimodal analgesic approach. Preoperative administration of gabapentinoids has been associated with a decrease in postoperative pain, nausea/vomiting, and opioid consumption. However, caution should be exercised when using gabapentinoids in elderly patients due to an increased risk of sedation, delirium, new antipsychotic use, and pneumonia. For same-day discharge patients, gabapentinoids should generally be avoided due to potential adverse effects like sedation and dizziness.

Various intravenous nonopioid agents administered intraoperatively can further contribute to opioid-sparing analgesia. Ketamine, an N-methyl-D-aspartate (NMDA) receptor antagonist, possesses analgesic, sedative, and amnestic properties. It may be used as an adjunct to propofol in total intravenous anesthesia (TIVA) regimens and has the potential to reduce postoperative pain and narcotic requirements.[53] Dexmedetomidine, an alpha-2 adrenergic agonist, has sedative-analgesic properties and can also reduce opioid requirements and the minimum alveolar concentration (MAC) of inhalational anesthetics. Studies have explored its use for postoperative analgesia and sedation.[54] Intravenous lidocaine has analgesic, antihyperalgesic, and anti-inflammatory properties and has been investigated as an analgesia adjunct. However, a Cochrane review of 68 trials found that there was probably no difference in pain at 24 hours compared with placebo, and effects on return to bowel function, PONV, and opioid requirement were uncertain with a lidocaine drip.[55] Magnesium sulfate has also been shown to have analgesic effects and lower opioid consumption.[56] Perioperative systemic magnesium administration has been linked to reduced postoperative pain scores, decreased opioid consumption, and a lower incidence of shivering after general abdominal surgery.[57] In contrast to the use of these nonopioid analgesics, the routine administration of sedatives, particularly long-acting benzodiazepines, to reduce preoperative anxiety should be avoided due to their detrimental effects on postoperative recovery, such as delayed emergence from anesthesia.

Intraoperative Opioid Use

Opioids remain a cornerstone of intraoperative analgesia, with fentanyl, hydromorphone (Dilaudid), and methadone among the most frequently used agents. Choice of opioid is guided by pharmacokinetic profile, patient comorbidities, and surgical context. The American College of Surgeons underscores their established efficacy and familiarity in perioperative pain management.[58]

Enhanced recovery after surgery (ERAS) guidelines for gynecologic oncology recommend minimizing the use of high-dose or long-acting opioids to reduce postoperative opioid-related side effects. Although ultrashort-acting

opioids such as remifentanil allow rapid emergence, concerns regarding opioid-induced hyperalgesia limit their widespread adoption.[58]

Fentanyl is favored for its rapid onset and short duration, making it particularly useful for titration to surgical stimuli. Intraoperative fentanyl administration has been associated with reduced postoperative pain, decreased opioid requirements, and shorter hospital stays, without increasing adverse effects.[59] Typical intraoperative doses range from 1 to 5 μg/kg IV, titrated to effect.

Hydromorphone (Dilaudid) provides intermediate duration and potency, and is often administered near the end of surgery to extend postoperative analgesia. Standard IV dosing ranges from 0.2 to 1 mg every 2 to 3 hours, with adjustments based on age and organ dysfunction.[60] While hydromorphone decreases postoperative pain, it carries a higher risk of respiratory depression and longer hospital stays when compared with fentanyl.[59]

Methadone is a long-acting μ-opioid receptor agonist with additional NMDA-antagonist properties. Single intraoperative doses (0.1-0.3 mg/kg IV) have been shown to reduce postoperative pain and opioid consumption, with safety profiles comparable to short-acting opioids.[61–64] Methadone may be particularly advantageous in major surgeries or in patients at risk for chronic postsurgical pain, though careful monitoring is warranted due to potential QTc prolongation and sedation.[61–64]

Summary: Fentanyl, hydromorphone, and methadone are all effective intraoperative opioids. Fentanyl is preferred for rapid titration, hydromorphone provides reliable extended postoperative coverage, and methadone offers long-acting analgesia with potential opioid-sparing benefits. Selection should be individualized, balancing efficacy, duration, and risk profile.[58–60,62–64]

Total Intravenous Anesthesia (TIVA)

Total intravenous anesthesia (TIVA), especially regimens utilizing propofol, offers significant advantages in the context of enhanced recovery after surgery (ERAS) protocols for gynecologic procedures. A key benefit of TIVA is the potential for reduced postoperative nausea and vomiting (PONV). This is a critical factor in ERAS pathways, as minimizing PONV contributes directly to patient comfort and facilitates earlier mobilization and oral intake. The rapid pharmacokinetic profile of propofol, a cornerstone of many TIVA techniques, also contributes to a more predictable and faster recovery from anesthesia compared with some inhalational agents. While inhalational anesthesia is a common alternative, a comprehensive systematic review and meta-analysis supports the notion that TIVA can offer a more controlled emergence, which is particularly beneficial in the context of ERAS aiming for timely discharge and rehabilitation. The predictable recovery associated with propofol-based TIVA aligns well with the accelerated rehabilitation goals of ERAS, making it a valuable anesthetic option for gynecologic surgery patients within these enhanced recovery pathways.

Moreover, propofol-based TIVA is more effective than inhalational anesthesia in mitigating the increase in intraocular pressure (IOP) in patients undergoing laparoscopic surgery in the Trendelenburg position. In addition, some evidence suggests that avoiding inhalational anesthetic agents as part of a TIVA regimen may potentially lead to a reduction in cancer recurrence, although further research is needed in gynecologic malignancies.[65] Given these advantages, TIVA represents a valuable tool for optimizing intraoperative management and enhancing recovery within gynecologic ERAS protocols.

Target-Controlled Infusion (TCI)

Target-controlled infusion (TCI) is a computer-assisted method of IV drug delivery that uses pharmacokinetic-pharmacodynamic (PK/PD) models to achieve and maintain a chosen drug concentration in the plasma or at the effect site. A computer-controlled pump, programmed with drug-specific PK/PD parameters, automatically adjusts the infusion rate to reach and sustain this target, accounting for factors such as age, weight, sex, distribution, and elimination kinetics.[66–69]

TCI is widely used for agents like propofol and remifentanil and is standard practice in many countries for sedation and general anesthesia. Compared with manual infusions, it enables rapid titration, stable concentrations, and more precise control of drug effects. Systems can target plasma or effect-site concentration, with the latter often preferred when clinical effect lags behind plasma levels.[70,71]

Two main system types exist: open-loop, which predicts concentrations without real-time feedback, and closed-loop, which integrates physiological monitoring (eg, EEG-based indices) to adjust delivery in real time.[68,72] While well-established and safe, model selection is critical, as inappropriate PK/PD models can cause suboptimal dosing, particularly in children, elderly, or obese patients. Newer general-purpose models aim to improve applicability across diverse populations.[66,73]

Notably, a systematic review and meta-analysis has indicated that TCI within TIVA was associated with a lower incidence of postoperative cognitive dysfunction (POCD) and lower postoperative pain scores compared with inhalational anesthesia.[74] However, it is important to note that while TCI systems are widely available throughout the world, they have yet to be introduced commercially in the United States due to regulatory hurdles with the FDA.

Complete Reversal of Neuromuscular Blockade

Complete reversal of neuromuscular blockade (NMB) has been significantly advanced with the introduction of sugammadex, a chemically modified cyclodextrin that can rapidly and completely reverse even intense neuromuscular blockade induced by steroidal neuromuscular blocking agents like rocuronium and vecuronium. While sugammadex offers a more predictable return of neuromuscular function compared with traditional acetylcholinesterase inhibitors, quantitative neuromuscular monitoring is crucial to ensure adequate recovery.

Quantitative monitoring, using devices like acceleromyography (AMG), electromyography (EMG), or mechanomyography, provides an objective measurement of the train-of-four (TOF) ratio, which reflects the degree of neuromuscular recovery. A TOF ratio of ≥ 0.9, measured quantitatively, is the accepted threshold for acceptable recovery. However, relying solely on clinical signs of recovery or qualitative assessment using a peripheral nerve stimulator (which depends on visual or tactile estimation of muscle contractions) is inadequate to reliably determine if a patient has achieved a TOF ratio of 0.9 or greater.[75] Quantitative monitoring plays a vital role in guiding the use of sugammadex and confirming its effectiveness. While sugammadex can reverse neuromuscular blockade, residual paralysis can still occur. Therefore, monitoring with a

quantitative device ensures that the neuromuscular function has returned to a safe level (TOF ratio ≥ 0.9 or potentially higher) before tracheal extubation.

One notable benefit of using sugammadex for NMB reversal, especially in the context of gynecologic surgery, is its association with a decreased risk of postoperative urinary retention compared with the traditional method of neostigmine coadministered with glycopyrrolate, likely due to anticholinergic effects of glycopyrrolate.[76] While the use of sugammadex has increased globally, there are specific considerations, particularly in pregnant and lactating women and those using hormonal contraceptives. Sugammadex's large and polarized molecular structure is expected to limit placental transfer to the fetus and excretion into breast milk. Clinically, studies in pregnant women undergoing cesarean section and nonobstetric surgery have not shown obvious detrimental maternal or fetal outcomes, although data remain limited.[77] The interaction of sugammadex with other steroidal substances, such as progesterone, has been a theoretical concern, as sugammadex can bind to these molecules. However, clinical studies examining steroidal hormone levels after sugammadex administration have shown no significant adverse effects on progesterone levels. Despite this, it is recommended that anesthesia providers assess the risk of oral contraceptive failure induced by sugammadex preoperatively and provide counseling to women of childbearing age.

PONV Prophylaxis

Postoperative nausea and vomiting (PONV) is a common and distressing complication following gynecologic surgery, and a multimodal approach to its prophylaxis is strongly recommended. In the context of ERAS programs, preventing PONV is a key element to facilitate early oral nutrition, mobilization, and discharge.

Several factors contribute to the risk of PONV, including both laparoscopic procedures and gynecologic surgery being independent predictors. Certain anesthetic choices can also influence PONV. For instance, propofol, commonly used for induction and maintenance of general anesthesia, has a favorable antiemetic profile. Continuous target-controlled infusions of propofol may offer an additional benefit in reducing PONV incidence. Conversely, nitrous oxide has been associated with an increased rate of PONV in patients at high risk and may be omitted during laparoscopic gynecologic surgery to prevent PONV.[78]

For patients undergoing same-day discharge (SDD), strategic mitigation of PONV risk is crucial. Risk assessment using a validated tool like the Apfel score is recommended. Multimodal antiemetic prophylaxis with 2 to 3 antiemetics from different classes, administered preoperatively or intraoperatively, is considered the standard of care for SDD patients. A combination of serotonin antagonists (eg, ondansetron) and corticosteroids (eg, dexamethasone) may be used for most patients, while preoperative aprepitant or transdermal scopolamine are options for patients with higher Apfel scores (3 to 4). However, scopolamine should be used cautiously in elderly patients due to the increased risk of postoperative urinary retention and delirium. For breakthrough PONV, rescue antiemetics from a different class than the prophylactic drugs should be used.

The choice of anesthetic can also impact PONV in SDD. Propofol-based total intravenous anesthesia (TIVA) is associated with less PONV compared with inhalational agents without increasing time to tracheal extubation or PACU stay. When TIVA is not an option, inhalational agents combined with appropriate PONV prophylaxis can offer similar antiemetic effects.

DISCUSSION

The intraoperative phase is a pivotal moment where anesthesiologists can make a lasting impact on a patient's recovery, especially in gynecologic oncology. Given the complexity of these surgeries, often involving extensive resection of pelvic organs, lymph nodes, and other vital structures, patients are at high risk for complications such as infection and prolonged recovery, which can interfere with a patient's ability to start or continue cancer treatments. ERAS protocols are designed to prevent these issues and speed up recovery, helping patients get back to essential additional treatments like chemotherapy or radiation as soon as possible, with studies reporting decreases of up to 4 days in length of stay.

One of the key goals of ERAS in gynecologic oncology is to minimize the physiological stress of surgery. Maintenance of normothermia, multimodal analgesia, and opioid-sparing strategies are essential in this context. Traditional reliance on opioids can result in delayed recovery, constipation, ileus, and longer hospital stays. Reducing opioid consumption using regional anesthesia and nonopioid analgesics, such as acetaminophen, NSAIDs, gabapentinoids, ketamine, and magnesium, have led to an 80% reduction in opioid use in the first 48 hours postoperatively without compromising pain control. Furthermore, the use of Goal-Directed Fluid Therapy (GDFT), through dynamic monitoring and real-time adjustments to fluid administration, helps to optimize organ perfusion and prevent stressors, including hypovolemia, acute kidney injury, and fluid overload. In addition, integration of TIVA not only expedites recovery by reducing the incidence of PONV but also facilitates earlier mobilization compared with inhalational anesthetics.

One of the most profound impacts of ERAS is its ability to reduce hospital length of stay by addressing the root causes of delayed recovery: prolonged physiological stress, inadequate pain control, and postoperative complications such as infections and nausea. By minimizing these risks through evidence-based interventions, ERAS protocols create a smoother and faster recovery process. This is particularly important in minimally invasive gynecologic surgery, where patients often have the potential for quicker. Furthermore, careful consideration should be given to the degree and duration of the Trendelenburg position, often used in laparoscopic and robotic gynecologic surgeries, due to risks of atelectasis, reduced FRC, and elevated intraocular pressure. Finally, at the end of laparoscopic procedures using CO2 pneumoperitoneum, facilitating the expulsion of residual gas with pulmonary recruitment maneuvers is important for reducing postlaparoscopic shoulder pain.

CONCLUSION

In gynecologic surgery, the implementation of ERAS protocols offers transformative benefits that extend beyond the immediate surgical recovery phase. By emphasizing evidence-based strategies, anesthesiologists play a vital role in optimizing patient outcomes and improving recovery times. The use of advanced techniques in fluid management,

normothermia maintenance, multimodal analgesia, TIVA, neuromuscular blockade reversal, and PONV prophylaxis has been shown to significantly reduce complications, enhance patient satisfaction, shorten hospital stays, and reduced time to RIOT for oncology patients.[4,79]

Anesthesiologists play a pivotal role in the successful application of ERAS protocols, tailoring perioperative care to meet the unique needs of gynecologic oncology patients. By reducing opioid use, employing advanced anesthetic techniques, and using dynamic monitoring to guide fluid therapy and neuromuscular blockade management, they help minimize the risks of complications that can delay recovery and disrupt cancer treatment timelines.

As the evidence supporting ERAS continues to grow, the role of the anesthesiologist will remain critical in advancing the principles of this patient-centered approach to surgical care. Future research and clinical trials will undoubtedly provide further insights into how these practices can be refined and personalized, ensuring that all patients benefit from the optimized perioperative care that ERAS offers. Through the continued adoption and refinement of these protocols, anesthesiologists will continue to shape the future of surgical recovery, leading to improved patient outcomes and enhanced quality of life following gynecologic surgery.

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