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Optimizing Anesthetic Management for Laparoscopic Surgery: A Comprehensive Review

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Laparoscopy, as the most frequently chosen surgical technique in the world, carries specific complications and distinctions in anesthetic management. Complications of laparoscopy, particularly perceptible as disorders of the physiology of the cardiovascular, respiratory, and nervous systems, are caused by the specific technical conditions required for this type of operation. To facilitate surgical access and to clarify the surgical field, it is necessary to create a splenic emphysema, consisting of filling the peritoneal cavity with carbon dioxide (CO₂). This results in an increase in intra-abdominal pressure (IAP) and increased diffusion of CO₂ into the blood, causing a state of hypercarbia. The impact of these disturbances is of great importance in the pathological functioning of the above-mentioned organ systems. The anesthetist, in addition to the need to induce a state of general anesthesia, must be aware of and understand the pathological impact of increased intracranial pressure (ICP) and hypercarbia to adjust patient monitoring accordingly and implement appropriate treatment targeting the specific complications occurring during laparoscopy. Complications and contraindications important from the anesthetist's point of view are also described. The 51 articles and reference texts were used for this purpose, which, combined with the authors' knowledge and experience, is intended to be a valuable resource for use by anesthesiology staff. This article aims to explain the effects of laparoscopy on human physiology and to compare and contrast methods of airway management, mechanical ventilation, the type of muscle relaxation used, and postoperative management in patients undergoing laparoscopic surgery.

Keywords: **Anesthesiology • Cardiovascular System • Central Nervous System • Laparoscopy • Pneumoperitoneum • Ventilation**

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Introduction

The laparoscopic technique deserves special attention, as it is currently the most frequently used technique in general surgery in the world. It owes its advantage over laparotomy to the fact that it is a minimally invasive technique. This manifests itself in fewer complications such as infections, blood loss, postoperative pain, and adhesion formation. Because of this, it allows earlier mobility and a shorter hospital stay for patients undergoing surgery while consuming less analgesics. It may additionally be used as a diagnostic procedure only [1]. However, it is not a technique without weaknesses. Special skills are required of the surgeon as well as specific anesthetic management. It also carries many complications associated with both mechanical trauma and the creation of a specific environment in the human body, such as peritoneal emphysema. Its production by infusing CO₂ into the peritoneal cavity will result in a state of increased intra-abdominal pressure (IAP) and hypercarbia. Such a condition generates characteristic disturbances in the homeostasis of the human body, particularly affecting the functioning of the cardiovascular, respiratory, and nervous systems (both central and peripheral). An adequate and thorough understanding of the details of laparoscopic surgery, including the specific effects of peritoneal emphysema on human physiology, determines safe anesthesia and perioperative care. In addition, the anesthesiology team must be able to rapidly recognize and intervene in typical situations that are specific complications of laparoscopy. The essence of this article is to present the complications and the contraindications to laparoscopic surgery, relevant from the anesthetist's point of view. In addition, it presents the management of general anesthesia, focusing on the method of airway management, the type of mechanical ventilation, and the pattern of use of muscle relaxants. It also describes the perioperative management of pain and antiemetic therapy. For this article, we searched the available literature and selected 51 articles published between 1992 and 2024. Articles that were research papers considered only adult populations, so the perioperative management described in this article does not apply to the pediatric population. Due to the ongoing development of specific therapeutic approaches for selected complications, we have included studies that are in the preclinical research stages to illustrate potential directions in laparoscopy and the treatment of complications. Such a statement of recognized medical norms for the management of patients undergoing laparoscopy and new potential directions are an undoubted advantage of this article. Based on the above-mentioned available literature as well as the authors' knowledge and clinical experience, we have tried to create an article to better understand the nature of complications of laparoscopic surgery and their therapeutic options as well as to consider options in perioperative management. Because of this, the undoubted value of this article is the combination of the explanation of the pathophysiology

of the created peritoneal emphysema and the statement of methods of both anesthesia and perioperative management. That will enable understanding the specifics of such operations from the point of view of the anesthesiology staff.

Pathophysiology of Pneumoperitoneum

Pneumoperitoneum is an abnormal state affecting the physiology of all systems of the human body. These effects are primarily related to changes in intra-abdominal pressure and their subsequent effects on respiratory mechanics and gas exchange, as well as the chemical properties of CO₂ diffusing into the blood, causing a hypercarbia state. As the volume of gas accumulates within the peritoneal cavity, it can cause irritation and inflammation of the peritoneal lining, leading to general abdominal symptoms such as abdominal distension, tenderness, rigidity, and pain.

The following paragraphs describe the disruption to the physiology of the 3 main systems – cardiovascular, respiratory, and nervous system (both central and peripheral) – that carbon dioxide-induced peritoneal emphysema causes.

Effects of Peritoneal Emphysema on the Cardiovascular System and Visceral Circulation

The effects of peritoneal emphysema on the various components of cardiovascular hemodynamics are well described in the literature and appear as interacting compartments. Injection of CO₂ into the peritoneal cavity causes an increase in IAP, creating mechanical compression of veins and arteries. Compression of large veins, including the inferior vena cava, causes an increase in central venous pressure (CVP) while reducing venous return, which reduces cardiac preload. In contrast, compression of the abdominal arterial vessels increases systemic vascular resistance (SVR) manifested as an increase in mean arterial pressure (MAP). Elevated SVR and MAP results in an increase in cardiac afterload. These changes in cardiac preload and afterload decrease cardiac output (CO) and cardiac index (CI), leading to impaired organ perfusion [2,3]. In addition to mechanical compression, the chemical nature of CO₂ itself, causing hypercarbia, has an impact on the cardiovascular system. Hypercarbia induces a number of physiologically relevant changes, including a decrease in SVR, while pulmonary vascular resistance increases, raises blood pH, and impairs hemoglobin affinity impairing oxygen transport. It also has a depressive effect on the myocardium, promoting ischemia or arrhythmic incidents [2,4]. For this reason, it is crucial from the anesthetist's point of view to carefully monitor capnia and maintain its value according to the patient's clinical picture.

It should be recalled that an increase in IAP also alters heart rate (HR) function, causing bradycardia and tachyarrhythmia, as described in more detail in the paragraph on changes in the nervous system.

The cardiovascular changes described above result in impaired visceral perfusion. Abnormalities in visceral microcirculation and inadequate tissue oxygenation have clinical implications. During laparoscopic surgery, reduced renal perfusion results in a decrease in glomerular filtration rate (GFR), leading to noticeable oliguria [2-4].

Adequate filling of the vascular bed is an effective treatment to reduce cardiac output and impaired organ perfusion [5,6]. The most beneficial effect in improving hemodynamic parameters and visceral flow was achieved by increasing the vascular volume with colloid infusion, while pharmacological vasodilatation and sympathetic blockade proved ineffective.

In the context of emphysema-induced organ ischemia, it is important to be aware of the phenomenon of reperfusion injury. After deflagration, reactive oxygen species (ROS) are released into the blood and have tissue-damaging properties. The balance between the antioxidant and oxidant systems is disrupted, leading to oxidative stress. The protective effect of the α_2 -agonist dexmedetomidine against organ damage caused by ischemia and reperfusion has been discovered. In view of these properties, this anesthetic has been proposed as a drug to prevent reperfusion damage in patients undergoing laparoscopic surgery [7]. Similarly, the protective properties of glycine against post-reperfusion liver damage have been described [8].

The vascular complication of peritoneal emphysema – CO₂ embolism – should also be borne in mind. This can lead to clinical complications such as pulmonary edema, shock, stroke, or even cardiac arrest. It has been shown that lower intra-abdominal pressure can have a protective effect. In addition, it is recommended to use transesophageal echocardiography (TEE) to detect potential gas embolism during procedures that increase their risk [9]. In the event of an embolism, gas administration must be stopped immediately, the patient should be positioned lying on the left side, and ventilation with 100% oxygen started [2].

Respiratory Effects

CO₂-induced peritoneal emphysema leads to respiratory dysfunction. CO₂ entering the blood causes hypercarbia, increasing pulmonary vascular resistance (PVR) through vasoconstriction [2]. Therefore, to maintain normal blood capnia, excess CO₂ must be removed from the patient's blood by increasing the

minute ventilation on the ventilator [10]. When, despite this treatment, the end-expiratory CO₂ (CO₂) concentration continues to rise after 30 minutes, one of the surgical complications – subcutaneous emphysema – should be considered [2].

An undeniably important component of ventilation and gas exchange impairment is direct compression and disruption of chest mechanics through increased IAP. The diaphragm then moves in a cephalad direction, compressing the lung parenchyma; this is further increased when the patient is placed in the Trendelenburg position. Compression of the lung parenchyma leads to areas of atelectasis, resulting in a reduction in the volume of ventilated lung tissue. In addition, a decrease in lung compliance, impairment of chest elasticity, and an increase in airway pressure were observed. The above changes result in a lower functional residual capacity (FRC) and an impaired ventilation-to-perfusion ratio, leading to further hypoxemia [2,11,12].

It has been suggested that a method of ventilation called the “open lung” method is effective in eliminating atelectatic areas, thereby improving gas exchange and respiratory mechanics. This consists of a recruitment maneuver (RM), such as application of continuous positive airway pressure (CPAP) at 40 cmH₂O for 40 seconds [11], which results in aeration of atelectatic alveoli. The next step is the application of positive end-expiratory pressure (PEEP) at 5 to 10 cmH₂O, depending on the study, to keep the alveoli continuously open. In addition, using PEEP alone without RM improves aeration and breathing mechanics but does not improve blood oxygenation [11,12].

Neurological Effects

Neurological effects affect both the central nervous system (CNS) and the peripheral nervous system, as well as the autonomic and somatic systems. It is directly caused by nerve compression and indirectly by impaired venous outflow from the CNS; hypercarbia modulating the vascular resistance of the cerebral circulation is also important.

The impact of peritoneal emphysema on the CNS is manifested by changes in intracranial pressure (ICP) and cerebral perfusion pressure (CPP).

An increase in intra-peritoneal pressure results in an increase in ICP. Several interacting components contribute to this effect, such as compression of the inferior vena cava obstructing venous blood outflow from the head, including the CNS, vasodilatation of the cerebral circulation vessels due to retention of CO₂ used to smother emphysema, and compression of the lumbar venous plexus. Patients with head trauma causing an increase in ICP are particularly at risk [13]. In a randomized

controlled trial [14], high-pressure (14 mmHg) emphysema increased ICP in 20 out of 51 patients studied, while low-pressure (8 mmHg) emphysema increased ICP in only 7 out of 50 patients. Separate factors, such as increased intracranial pressure and the use of the steep Trendelenburg position, have been shown to contribute to increased intracranial pressure by impairing venous outflow. However, the use of PEEP=8 cm-H₂O (with ventilation of 8 ml/kg of ideal body weight) did not exacerbate the further increase in ICP induced by emphysema (insufflation pressure 15 mmHg) and the Trendelenburg position with a slope of 35° [15]. As volume and thus intracranial pressure increases, CPP decreases. The decrease in cerebral perfusion is moreover influenced by the decrease in cardiac index induced by emphysema [16]. In anesthesia, it is crucial to maintain normocapnia by adequately adjusting the respiratory rate. This will stabilize intracranial homeostasis, which may prevent long-term significant neurological problems [17].

The impact on the autonomic nervous system has not been explicitly investigated. The physiological stress response induced by pneumoperitoneum can affect the autonomic nervous system, leading to changes in sympathetic and parasympathetic activity. This can result in alterations in HR, blood pressure (BP), and SVR, potentially affecting overall systemic hemodynamics. Clinical studies [18-20] have shown that pneumoperitoneum results in a predominance of sympathetic nervous system tone, as measured by an increase in heart rate variability (HRV). Interestingly, emphysema induced by a lower pressure (7 mmHg), results in significantly reduced sympathetic activation than standard-pressure emphysema (12 mmHg) [18], and this can increase risk of ventricular arrhythmias among patients with cardiac diseases [19].

Blowing CO₂ into the abdominal cavity can increase vagus nerve tension, resulting in bradyarrhythmias, with the possibility of asystole [2]. A retrospective cohort study [21] found that bradycardia is a common complication of laparoscopic surgery and is managed by stopping gas insufflation, emptying the abdominal cavity, and administration of atropine. Careful monitoring of the patient and sometimes the inclusion of supportive treatment is essential [22].

The increased intra-abdominal pressure can compress peripheral sensory nerves within the abdominal wall, leading to sensations of discomfort, pain, or referred pain that may be perceived in other regions of the body. Interestingly, it has been reported that 19 out of 90 patients operated on laparoscopically experienced postoperative shoulder-tip pain, especially on the right side. This is further explained by the irritating effect of CO₂ on the diaphragm, overstretching of its muscle fibers, or stretching of the intra-abdominal cavity [23]. Some of these patients are very likely to require additional postoperative pain therapy.

It is essential to monitor neurological parameters, especially in patients with pre-existing neurological conditions or injuries, to ensure optimal neurological function and prevent any adverse neurological events during and after surgical procedures involving pneumoperitoneum. Such patients are especially susceptible to ICP increases; in such circumstances, diagnosis by transcranial Doppler (TCD) is recommended [17].

Contraindications for Laparoscopic Operation

The risks associated with laparoscopic surgery can be categorized as patient-specific, surgical, positional, or those arising from the altered physiology due to the creation of pneumoperitoneum. Laparoscopic surgery should never be considered “routine” or “low risk,” as complications tend to be more insidious compared to traditional open techniques [24].

Laparoscopic surgery has traditionally been contraindicated in patients experiencing hemodynamic shock, acute intestinal obstruction (due to the risk of perforation from dilated bowel loops), and increased ICP. Relative contraindications include cardiac or respiratory failure, as the creation of pneumoperitoneum can increase myocardial workload and oxygen demand, potentially leading to myocardial infarction, and can also cause respiratory acidosis. Pregnancy is another relative contraindication, largely due to the reduced intra-abdominal space and other considerations [25,26]. In the first trimester, laparoscopic surgery is contraindicated because of the risk of teratogenicity from anesthetics. In the third trimester, the risk of premature delivery makes the procedure inadvisable. The second trimester (13-26 weeks) is relatively safer for laparoscopic surgery, although some studies indicate a higher risk of fetal loss associated with laparoscopic appendectomy compared to open surgery [24]. The remaining risks include infections at port sites, adhesions from previous abdominal surgeries, and diagnosed abdominal aortic aneurysm. However, the risk to the individual patient must be balanced between the risk of complications due to the position, duration, degree of CO₂ absorption, and physiological effects of pneumoperitoneum for a particular laparoscopic procedure, versus the shortened postoperative recovery time, which may outweigh the increased intraoperative risk. Generally accepted contraindications include pre-existing raised intracranial pressure, severe uncorrected hypovolemia, and patients with known right-to-left cardiac shunts or a patent foramen ovale [27].

Perioperative Management

Airway Management

The most common device used for airway management and ventilation is the endotracheal tube (ETT), which is considered the

criterion standard for laparoscopic surgery, but it is relatively invasive. In recent years, less invasive supraglottic airway devices (SAD) such as the laryngeal mask airway (LMA) or i-gel have been developed. The use of LMAs in surgeries is increasing, but there are some concerns about SAD, mainly related to regurgitation and risk of pulmonary regurgitation or inadequate ventilation [28,29].

Yilmaz et al [28] compared the applicability and differences between LMAs (LMA Protector) and ETTs in patients undergoing laparoscopic cholecystectomy. In addition to the easier placement of LMAs relative to the intubation procedure, they caused less postoperative damage to the larynx and trachea, resulting in less postoperative soreness. They have a better hemodynamic profile, as evidenced by higher HR values after device insertion and emphysema creation and an increase in MAP after extubation when ETTs are used, which is explained by greater adrenergic stimulation. Importantly, use of this type of mask did not increase the risk of barotrauma and leakage, as peak inspiratory pressure (PIP) values were comparable to those of endotracheal intubation, and mean oropharyngeal leak pressure (OLP) values were above 30 mmHg.

Chih-Jun Lai et al [29] established the high effectiveness of i-gel masks during laparoscopic gynecological surgery in the inverted Trendelenburg position. The advantage of i-gel devices over conventional endotracheal intubation was lower airway resistance and less postoperative pain in the throat area. Furthermore, similar ventilation efficiency and no signs of aspiration were demonstrated as with ETTs. The above studies suggest that in many cases of laparoscopic surgery, SADs can be as effective an alternative as ETTs, providing greater postoperative patient comfort.

However, the use of LMAs has limitations. One study recommends using LMAs instead of ETTs for laparoscopic cholecystectomies only if certain criteria are met: patients classified as ASA 1-3, scheduled for elective laparoscopic surgery, non-obese (body mass index – BMI <30 kg/m²), and with pneumoperitoneum pressure lower than 13 mmHg. Additionally, the LMA used should have a drain channel, and performing a prophylactic routine gastric aspiration may help minimize the risk of regurgitation and ensure proper exposure of the surgical field. Patients who do not meet these criteria will likely benefit more from using an ETT rather than an LMA [30].

Ventilation Pressure-Controlled or Volume-Controlled

The most common method used in surgeries is volume-controlled ventilation (VCV) [31]. In laparoscopic operations, comparing VCV and pressure-controlled ventilation (PCV) reveals key differences in respiratory management. PCV often provides better intraoperative oxygenation due to improved alveolar

recruitment. However, studies indicated no significant difference between PCV and VCV in preventing postoperative pulmonary atelectasis. Research involving morbidly obese patients undergoing laparoscopic gastric sleeve surgery shows that PCV results in higher intraoperative oxygen levels: partial pressure of oxygen and oxygen saturation of arterial blood (PaO₂ and SaO₂, respectively) than VCV, but both methods yield similar outcomes for postoperative oxygenation and atelectasis, a complication of intra-abdominal emphysema. Therefore, the choice between PCV and VCV should consider intraoperative benefits and patient-specific factors, as both techniques are effective in preventing postoperative complications [32].

In laparoscopic surgeries, both VCV and PCV appear equally suitable for most healthy patients without comorbidities. However, in certain patient populations, PCV has shown advantages. The parameters used to compare the methods include hemodynamic and respiratory factors.

In elderly patients undergoing laparoscopic interventions on bile ducts with LMA, PCV provided ventilation with lower peak inspiratory pressure and greater dynamic compliance [33]. PCV mode has further been proven to provide better oxygenation in patients undergoing laparoscopic cholecystectomy [34]. Furthermore, for patients undergoing laparoscopic surgery in Trendelenburg position, PCV was shown to provide ventilation with lower peak inspiratory pressure and greater dynamic compliance [35].

Use of Muscle Relaxants for Laparoscopy

The use of muscle relaxation aims to provide better conditions to surgeons by minimizing sudden movements and increasing intra-abdominal space. The most common approach is to use a moderate or standard neuromuscular block (1 dose of induction muscle relaxants). However, the alternate approach is the use of deep neuromuscular blockade, which has shown some advantages. The EURO-RELAX TRIAL study [36] demonstrated that deep neuromuscular blockade (NMB) provides better surgical conditions compared to standard NMB, which is particularly crucial in complex laparoscopic procedures. Standard NMB is sufficient for less complex procedures such as laparoscopic cholecystectomy, appendectomy, and simple diagnostic procedures. In contrast, deep NMB is recommended for more complex procedures, including cancer surgery, bariatric surgery, laparoscopic reconstructions, and robotic procedures. The use of deep NMB minimizes sudden perioperative movements, improving conditions for surgeons and reducing the risk of tissue injury. While deep NMB can significantly enhance operative conditions during complex laparoscopic procedures, it also necessitates more extensive monitoring and careful management of the neuromuscular blockade. Furthermore, using deep neuromuscular blockade allows for the maintenance of intra-abdominal pressure at a lower level compared to standard

neuromuscular blockade. This reduction in intra-abdominal pressure can decrease the risk of organ damage associated with high pressures [10]. The depth of neuromuscular blockade is typically measured through stimulation of the ulnar nerve and assessing the muscular response. Two patterns of stimulation are typically used – train-of-four (TOF) and post-tetanic count simulation (PTC). “Classically”, the standard neuromuscular blockade has been a TOF of 1-2. However, recent studies show that for deep neuromuscular blockade, a TOF target of 0 is ideal along with a PTC of less than 5 [37]. Another systematic review had 3 main findings. First, there is strong evidence (recommendation grade A) that the use of deep NMB compared with moderate NMB optimizes surgical conditions during laparoscopic cholecystectomy, hysterectomy, and nephrectomy/prostatectomy. Although deep NMB slightly improves surgical conditions during laparoscopic cholecystectomy performed with low-pressure pneumoperitoneum (8 mmHg), ensuring acceptable conditions may require an increase in intra-abdominal pressure in up to half of patients, regardless of the level of NMB. Second, moderate NMB improves surgical conditions in some cases during radical retropubic prostatectomy, although good to excellent conditions can be achieved even without NMB. Third, deep NMB (PTC 0-2) is recommended for laparoscopic cholecystectomy, nephrectomy, and prostatectomy to improve surgical conditions, while there is insufficient evidence to determine the optimal level of NMB for laparotomy [38].

Postoperative Management

After the surgery, patients usually experience maximal pain in the first 2 hours. It is necessary to provide them with appropriate analgesia, oxygen, and (if needed) antiemetics. Postoperative care following laparoscopic surgery is crucial for ensuring a smooth recovery and minimizing complications. Effective management of postoperative pain is a primary focus, as pain can significantly impact patient recovery and satisfaction; therefore, various strategies in pain prevention and treatment are employed [39].

Additionally, maintaining optimal intra-abdominal pressure during surgery is essential to prevent postoperative complications. Lower intra-abdominal pressure achieved through deep neuromuscular blockade has been associated with a reduced risk of organ damage, highlighting the importance of appropriate anesthetic and pressure management strategies [40].

Enhanced Recovery After Surgery (ERAS) Protocol in Laparoscopic Operations

The ERAS protocol is becoming more widely and readily used in surgery and perioperative care of patients. It combines a complex of preoperative, perioperative, and postoperative

procedures that aim to reduce postoperative discomfort and shorten the length of hospital stay after surgery. In addition to general surgery, good results have been described using its principles in patients undergoing laparoscopy. In a study group of 90 patients undergoing laparoscopic hysterectomy, it influenced the optimization and acceleration of recoalescence, without a concomitant increase in complications and readmissions [41]. Dominguez et al also demonstrated that the use of the ERAS protocol in laparoscopic radical cystectomy with of 1 ileal conduit resulted in shorter hospital stays and fewer readmissions. In addition, they noted a reduction in the number of days patients maintained a nasogastric tube and a shorter length of stay in the Intensive Care Unit (ICU) [42]. The conduct of the ERAS protocol, as mentioned above, should already be introduced before surgery, which requires informing the patient in advance to explain the various components of the protocol and its relevance. Also, before the procedure, no mechanical bowel preparation is recommended and a 6-hour fasting period is instituted for solid foods and 2 hours for clear liquids. During the operation, it is important to maintain euolemia with balanced fluids, where the optimal flow rate for laparoscopic surgery has been set at 3-5 ml/kg/h. Also, it is necessary to keep the patient warm to maintain the temperature within $36^{\circ}\text{C} \pm 0.5$, and to provide antibiotic and anticoagulant prophylaxis (compression stockings). Drains and nasogastric tubes are not recommended, and induction and maintenance of anesthesia should be carried out with short-acting agents, which is important from the anesthesiologist's point of view. For 2 hours after surgery, FiO_2 must be maintained at 0.5, and fluid therapy must be administered restrictively with balanced fluids. Oral intake should be introduced as early as 6 hours, optimally within 24 hours. Patient mobilization takes place on the first postoperative day, and the bladder catheter is recommended to be removed within 24-48 hours. Pain therapy and treatments to prevent the onset of postoperative nausea and vomiting (PONV) are critically important in following ERAS in the context of laparoscopic procedures, as described in more detail in the following paragraphs [41,43].

Analgesia and Pain Management

Pain after laparoscopic surgeries can be severe and persistent, and every patient should receive appropriate analgesia. Three types of pain can be distinguished after laparoscopy: incisional, nociceptive, and visceral pain; inflammatory pain (as a result of tissue injury); and neuropathic pain. Single-treatment pain management is very rare; usually, a multimodal pain management protocol is used. For mild to moderate pain, it is recommended to use paracetamol and nonsteroidal anti-inflammatory drugs (NSAIDs). In addition, NSAIDs along with glucocorticosteroids are dedicated to controlling the inflammatory component of pain. In case of severe pain, opioids are

more effective [44]. Local anesthetics, like bupivacaine injected into trocar wounds during surgery can, result in a reduction of abdominal wall pain by 1-1.5 points (on a pain scale of 0-10) [41,44]. Some patients, whose response to pain is worse or when higher doses of opioids are contraindicated, may need the addition of adjuvant compounds such as dexmedetomidine or ketamine [40-44]. Proper analgesia is also essential for earlier patient discharge [41,44].

The PROSPECT working group issued recommendations developing anesthetic, analgesic, or surgical interventions in the background of laparoscopic cholecystectomy based on systematic reviews and randomized controlled trials (RCTs) [45]. According to the GRADE consensus, it is recommended to administer oral paracetamol and nonsteroidal anti-inflammatory drugs (NSAIDs) or cyclooxygenase-2 (COX-2) inhibitors preoperatively (GRADE A). If these medications are not given before the surgery, they can be administered intravenously (GRADE A and B). Continuing the use of paracetamol and NSAIDs postoperatively is also recommended (GRADE A). This review extends these recommendations to include the pre- and intraoperative periods and introduces the use of a laparoscopic miniport (GRADE B). Preoperative gabapentinoids and the intraoperative use of topical lidocaine are not routinely recommended (GRADE D). Instead, local saline lavage with adequate venting of the peritoneal emphysema is advised (GRADE A). Techniques such as epidural anesthesia and spinal block are not recommended due to limited evidence and potential complications (GRADE D).

In the context of the ERAS protocol, in addition to the aforementioned nasal wound anesthesia, there is a clear stance on limiting the use of opioid drugs due to their adverse effects, which primarily include nausea, vomiting, constipation, or postoperative sleep disturbances (PSD), and replacing them with non-opioid drugs. After surgery, analgesia should be administered orally on an individualized basis, depending on the patient's preference and pain level [41,43]. Moreover, in gynecological laparoscopic procedures, non-opioid anesthesia (with esketamine and dexmedetomidine used) was not inferior in terms of analgesic effect and stability of anesthesia during surgery to classical opioid techniques (with sufentanil and remifentanil used). Non-opioid techniques, although they resulted in prolonged wake-up time and return to orientation, contributed to a reduction in the occurrence of PONV and improved the quality of postoperative sleep [43].

Prevention of Postoperative Nausea and Vomiting (PONV)

Postoperative nausea and vomiting (PONV) occur within 24 hours after surgery. Laparoscopic surgery is itself associated with an increased risk of PONV. Also, the risk of their occurrence depends on the patient's personal factors, surgical interventions,

and anesthesia – the occurrence is favored by the use of nitrous oxide, neostigmine, or opioids. Therefore, effective prevention and treatment are crucial. Effective treatment options include metoclopramide, ondansetron, and dexamethasone, which not only work well in patients requiring opiates but also help reduce pain and shorten hospital stay. Studies highlight the importance of a multifaceted approach to prevent vomiting during laparoscopic surgeries, combining pharmacological and non-pharmacological methods tailored to individual patient needs [46]. A study by Zhong et al [46] analyzing 90 cases of patients undergoing laparoscopic gynecological, urological, and general surgery operations suggests that an effective strategy for preventing PONV is the combination of ondansetron, dexamethasone, and acupressure at the P6 point. This combination significantly reduces the incidence of PONV and the need for rescue antiemetics compared to palonosetron alone, with notable benefits observed at 6 and 12 hours postoperatively.

Various antiemetic medications such as dexamethasone, ondansetron, and ramosetron have been studied for their effectiveness. Dexamethasone combined with ramosetron has been shown to significantly reduce the overall incidence of nausea during the first 48 hours after surgery. Additionally, the timing and dosage of antiemetics play a crucial role, as administering dexamethasone at the beginning of surgery and ondansetron towards the end can optimize the antiemetic effects. Adjusting doses based on patient-specific factors, such as weight and risk profile, is also recommended [47].

According to the recommendations of the ERAS protocol, to prevent PONV, in addition to the aforementioned pharmacotherapy, a carbohydrate-rich diet the day before surgery, shortened fasting with fluids to 2 hours before surgery, and early mobilization of the patient after surgery are recommended. In a further addition, limiting opioid usage due to its emetogenic effects is a proven preventive measure [48,49]. This is supported by a previously cited study showing that opioid-free anesthesia in gynecologic laparoscopy resulted in, among other things, a reduction in the incidence of PONV compared to anesthesia with opioids [43].

Complications

Beyond the complications described in the first part of the article, which arise from the creation of pneumoperitoneum and hypercarbia, we can also distinguish traumatic complications resulting from surgical activity and the specificity of laparoscopic procedures [48].

Traumatic complications related to the introduction of needles or trocars primarily include bleeding and damage to the intestines and visceral organs. Bleeding can occur from the anterior

Table 1. Complications of laparoscopic surgery related to pneumoperitoneum and hypercarbia.

Venous return and CO and CI decrease
MAP increase
Changes in SVR, increase in pulmonary vascular resistance
Arrhythmias – bradycardia, tachyarrhythmias
Impaired tissue perfusion (myocardial ischemia, GFR decrease)
Oxidative stress
Hypercapnia, acidosis and impaired oxygen transport
CO ₂ embolism
Atelectasis, FRC decrease, impaired ventilation-to-perfusion ratio
Hypoxemia
Impairment of chest elasticity, lung compliance decrease, and airway pressure increase
ICP increased and CPP decrease, cerebral vessels vasodilatation
Pain complaints
Regurgitation, vomiting, aspiration of gastric contents, PONV

CO – cardiac output; CI – cardiac index; SVT – systemic vascular resistance; MAP – mean arterial pressure; GRF – glomerular filtration rate; CO₂ – carbon dioxide; FRC – functional residual capacity; ICP – intracranial pressure; CPP – cerebral perfusion pressure; PONV – postoperative nausea and vomiting.

abdominal wall at the site of trocar insertion, from the tearing of adhesions and scar tissue during the introduction of gas into the peritoneal cavity, and from damaged blood vessels. As a result, during laparoscopy, even significant vascular injury may go unnoticed, especially complications like venous tamponade and retroperitoneal hematomas may not be diagnosed until after surgery. In extreme cases, the abdominal aorta may be damaged by the Veress needle or trocar. Bleeding is thought to be the most common cause of rare death during laparoscopy, which is, however, a rare complication [27,48]. As it is not possible to palpate the pulsating vessel during laparoscopy, techniques have been introduced to visualize the vessels. However, the proposed methods of Doppler ultrasonography or near infrared vein visualization had some limitations. To circumvent these, an intelligent system that detects vascular and non-vascular areas by detecting differences in total hemoglobin (HbT) and oxygen saturation (StO₂) between tissues was investigated in preclinical studies [50].

The Veress needle or trocar may directly penetrate the intestine, with perforation usually involving the colon and less frequently

Table 2. Complications of laparoscopic surgery related to related to mechanical damage.

Bleeding from a damaged vessel, hematomas
Perforation of the gastrointestinal wall – peritonitis, abscesses, septic shock
Pneumothorax
Subcutaneous emphysema
CO ₂ embolism
PONV
Postoperative pain

CO₂ – carbon dioxide; PONV – postoperative nausea and vomiting.

the small intestine. Intestinal damage (particularly small and thus often unnoticed) can lead to peritonitis, the formation of inter-loop abscesses with a septic reaction. In such circumstances, proper diagnosis is often delayed, leading to extremely severe secondary complications and high mortality [48].

A mechanical complication of a misplaced trocar may also be pneumothorax; interestingly, an increase in IAP, the presence of a pleuroperitoneal fistula, or increased CO₂ absorption may also contribute to its formation [49] Subcutaneous emphysema occurs when trocars are placed outside the peritoneal cavity, or the continuity of fascial laminae is interrupted [2]. Furthermore, the gas embolism described in the first part of this article is also a complication of, among other things, direct damage to the vessel [9].

Prolonged steep Trendelenburg positioning heightens the previously described risk of cerebral and upper airway edema and exacerbates ventilation and perfusion mismatch. Additionally, prolonged surgery in this position can lead to “well leg compartment syndrome,” a rare but serious complication [27].

A complication caused by development of peritoneal emphysema is the backflow of acidic digestive contents from the stomach. The possibility of aspiration of acidic gastric contents has been associated with the Trendelenburg position and pneumoperitoneum, especially in obese patients. However, it appears that the incidence of this complication is low, as these operations are usually performed electively, and the tension of the lower esophageal sphincter increases in response to rising intra-abdominal and gastric pressures. This mechanism reduces the possibility of regurgitation, vomiting, and, consequently, aspiration syndrome. To enhance safety, it is recommended to administer metoclopramide orally or parenterally before the procedure. This medication can increase the tension of the lower esophageal sphincter and reduce the frequency of regurgitation and aspiration. For patients with reflux, metoclopramide

or omeprazole is administered to lower the pH of gastric juice and minimize the effects of accidental aspiration.

Approximately 2-3% of all laparoscopic operations end in conversion, meaning the procedure is extended to an open laparotomy due to complications or the inability to perform the operation laparoscopically [48]. Adverse effects due to emphysema formation and mechanical surgical complications are included in **Tables 1 and 2**, respectively.

Conclusions

Laparoscopic surgery, involving the creation of pneumoperitoneum, significantly impacts physiological systems, necessitating careful anesthetic management to mitigate adverse effects. Cardiovascular impact includes increased intra-abdominal pressure compressing veins and arteries, raising central venous pressure and peripheral vascular resistance. This compression reduces cardiac preload and increases afterload, leading to decreased cardiac output and impaired organ perfusion. CO₂ absorption induces hypercarbia, increasing pulmonary vascular resistance and causing myocardial depression. Monitoring capnia and maintaining appropriate intra-abdominal pressure are crucial. Respiratory impact involves elevated intra-abdominal pressure compressing the diaphragm, reducing lung compliance and ventilation efficiency, potentially leading to atelectasis and hypoxemia. Techniques like the “open lung” method, with recruitment maneuvers and PEEP, can improve lung aeration and gas exchange. Neurological impact includes increased intracranial pressure due to impaired venous outflow and CO₂-induced cerebral vasodilation. Maintaining normocapnia through a ventilation rate appropriate to the clinical situation is essential to stabilize intracranial pressure. Sympathetic tone may increase, potentially causing bradyarrhythmias from vagus nerve stimulation. Absolute contraindications for laparoscopic surgery include hemodynamic shock, acute intestinal obstruction, and increased intracranial pressure. Relative contraindications involve cardiac or pulmonary failure and pregnancy, particularly in the first and third trimesters. Perioperative management includes airway control, where SADs can often be an equivalent alternative to ETTs. Volume-controlled and pressure-controlled ventilation methods both have advantages, with pressure-controlled ventilation benefiting certain populations like the elderly and obese. Deep neuromuscular blockade improves surgical conditions and allows lower intra-abdominal pressures, reducing systemic complications. Postoperative management focuses on effective pain control through multimodal analgesia, including paracetamol, NSAIDs, opioids, glucocorticosteroids, use of adjuvants, and local anesthetics infiltrations. Antiemetic strategies, using medications like ondansetron or dexamethasone and opioid avoidance, are crucial for managing postoperative

nausea and vomiting. Following the ERAS protocol in patients undergoing laparoscopy can enable faster recovery and discharge from the hospital. In conclusion, anesthesia for laparoscopic operations requires understanding the physiological impacts of pneumoperitoneum and meticulous perioperative management to ensure patient safety and optimal outcomes.

Future Directions

A thorough understanding of the mechanisms by which peritoneal emphysema disrupts systemic homeostasis is important in several key areas. Optimizing IAP management is crucial, with studies aiming to determine the optimal IAP levels that balance surgical needs with minimal physiological disruption. Personalized IAP settings based on factors such as age, comorbidities, and BMI could help minimize complications. Improved monitoring techniques, such as advanced TEE and non-invasive ICP monitors, can enhance the detection and management of complications like CO₂ embolism and cerebral perfusion changes. Real-time monitoring could provide early warnings for timely interventions. Research on ventilation strategies should compare volume-controlled and pressure-controlled ventilation in different patient populations, including those with pre-existing respiratory conditions. This could refine guidelines for optimal ventilation management and help assess the long-term effects on postoperative outcomes. In addition, efforts should be made to popularize the use of SAD instead of classical endotracheal intubation, as these methods are not inferior in efficacy in some cases, additionally providing more favorable hemodynamic parameters and postoperative comfort of patients. Investigating the efficacy of pharmacological agents like dexmedetomidine and glycine in preventing complications during and after laparoscopic surgery could improve care protocols. Exploring novel antiemetic combinations or prophylactic measures for PONV may enhance patient recovery. Further research into deep NMB in complex laparoscopic procedures could establish more precise guidelines. Evaluating the safety and effectiveness of various NMB depths, especially in patients with specific contraindications, would also be valuable. Developing nuanced guidelines for contraindications to laparoscopic surgery, particularly for patients with cardiovascular, neurological, or respiratory vulnerabilities, could improve outcomes. A comprehensive risk stratification model incorporating real-time data and patient history could guide surgical planning. Exploring multimodal analgesia approaches, including local anesthetics, NSAIDs, and adjuvants, could enhance postoperative pain management. Longitudinal studies on different analgesic protocols could inform best practices. Research into minimally invasive techniques and their efficacy compared to traditional methods could advance surgical care. Clinicians should be encouraged to implement a perioperative ERAS protocol in patients undergoing laparoscopy, enabling faster recovery.

Encouraging interdisciplinary collaborations between anesthesiologists, surgeons, and critical care specialists could develop comprehensive perioperative care guidelines. Regular updates incorporating the latest evidence and advancements would ensure optimal patient care. These directions highlight the need for ongoing research and innovation to address the complex challenges of pneumoperitoneum and laparoscopic surgery, ultimately enhancing patient safety and outcomes.

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