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Understanding the effects of laparoscopy on hemodynamics and mitigating complications: An anesthetic approach for gynecological surgery

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Abstract

Laparoscopic surgeries have become popular and are now widely used in gynecological procedures due to their minimally invasive nature. CO_2 is used to create the pneumoperitoneum to facilitate the laparoscopic surgery. Pneumoperitoneum and different positions used can have adverse effects on hemodynamics. Most of the system of the human body are affected including Cardiovascular and pulmonary system leading to various complications. Complications include vascular and bowel injury during pneumoperitoneum access, subcutaneous emphysema, pneumothorax, pneumomediastinum, CO_2 embolism and others. Understanding the underlying hemodynamic changes is crucial to tailor the patient's individual needs. Anesthesiologists play a critical role in managing these challenges by closely and vigilantly monitoring hemodynamics, utilizing appropriate anesthetic techniques, and promptly identifying and addressing potential complications. This paper aims to provide a comprehensive review of the effects of laparoscopy on hemodynamics, expected complications, its management and the current anesthetic approaches used to mitigate these effects in laparoscopic gynecological surgery including postoperative pain management.

Keywords: Complications; Gynecological surgery; Hemodynamics; Laparoscopy

1. Introduction

Laparoscopy has become a widely used surgical technique for the diagnosis and treatment of gynecological conditions. One can enjoy multiple benefits by opting for a minimally invasive approach over the traditional open surgery. These advantages include less postoperative pain, shorter hospitalization periods, and quicker recovery times. [1] However, laparoscopy still carries some risks, particularly in relation to the hemodynamic changes that occur during the procedure and the effects of anesthesia on the patient. In this topic, we will explore the hemodynamic changes that can occur during laparoscopy and the potential complications that may arise as a result, as well as the various anesthesia techniques used during laparoscopic gynecological surgery. We will examine the benefits and drawbacks of different anesthesia methods, as well as strategies for minimizing the risks associated with laparoscopy and anesthesia.

Hemodynamic changes during laparoscopy is due to

- Pneumoperitoneum
- Patients position
- Absorbed carbon dioxide (Co_2)

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1.1. Physiological effect of pneumoperitoneum.

CO_2 is used to insufflate the abdomen and create pneumoperitoneum to facilitate the laparoscopic surgery. The abdominal cavity has a normal pressure range of 0-5 mm Hg, referred to as intrabdominal pressure (IAP). When the IAP exceeds 10 mm Hg, it is deemed significant from a medical perspective, as it can lead to complications in various organs. Sustained IAP greater than 12 mm of Hg is defined as Intra-abdominal hypertension. At an IAP of over 15mm Hg, the effects on organ system increases and above 20 mm of Hg a potentially severe condition called abdominal compartment syndrome can arise, which can harm multiple organ systems.

1.1.1. Cardiovascular system

Intra-abdominal pressure increases due to pneumoperitoneum. As a result, there is peripheral pooling of blood at lower extremities, caval compression and increase in vascular resistance of intrabdominal organs. Following the initial brief increase in preload, there is a subsequent decrease in preload and cardiac output (CO). This decrease is more significant and sustained compared to the initial increase.CO typically decreases by 10 to 30% when intra-abdominal pressure exceeds 10mmHg. Systemic vascular resistance (SVR) and pulmonary vascular resistance (PVR) is increased due to sympathetic activation and neuroendocrine response to pneumoperitoneum. Heart rate is unchanged.

To calculate the mean arterial pressure (MAP), one needs to multiply the cardiac output (CO) by the systemic vascular resistance (SVR). MAP=CO X SVR

The overall increase in MAP (mean arterial pressure) is due to a greater increase in SVR (systemic vascular resistance) compared to the decrease in CO. Generally, healthy individuals can handle these changes in hemodynamics without any issues. However, patients with pre-existing cardiac conditions may be more vulnerable to experiencing additional cardiac complications.

When the peritoneum is stretched during surgery, it can lead to reflex vagal stimulation, which in turn may cause various cardiac complications such as bradycardia, cardiac arrhythmia, and, in rare cases, asystole. Asystole is typically associated with severe complications such as gas embolism, severe hypoventilation and acidosis. Although different types of arrhythmias have been reported, life-threatening arrhythmias are infrequent.

To minimize the above-mentioned effects, certain measures can be taken. These include using the lowest possible insufflation pressure required for adequate exposure during surgery, aiming for an insufflation pressure below 15 mm Hg, inducing pneumoperitoneum in the supine position and limiting the intra-abdominal pressure to 12-15 mm Hg to minimize cardiovascular function alterations.[2] Slow insufflation of CO_2 can also help decrease the risk of arrhythmias. If bradycardia occurs, insufflation should be stopped, and the use of atropine and deepening of anesthesia should be considered. Vasodilating agents, centrally acting alpha-2 agonists, or opioids may be used to treat increases in systemic vascular resistance. Prior to the induction of pneumoperitoneum, appropriate intravenous fluid loading can help attenuate decreases in venous return and CO.

1.1.2. Respiratory changes

The induction of pneumoperitoneum during surgery can lead to several physiological changes in the respiratory system. These changes include a cephalad shift in the diaphragm, stiffening of the lower chest wall, and a reduction in thoracopulmonary compliance. This reduction is more significant in patients who are obese and those belonging to American Society of Anesthesiology (ASA) class III or IV. The Trendelenburg position, which is commonly used in gynecological procedures, further exacerbates this increase in intrathoracic pressure by compressing the diaphragm. As a result of this compression, the functional residual capacity (FRC) of the lungs decreases, leading to atelectasis. Atelectasis alters the normal relationship between ventilation and perfusion of the lungs, resulting in hypoxemia. Older patients are particularly vulnerable to atelectasis, as their closing capacity increases with age. To prevent atelectasis and maintain FRC, positive end-expiratory pressure (PEEP) can be used to stent alveoli open at end expiration. Furthermore, controlled mechanical ventilation during laparoscopic surgery can be challenging due to the decrease in thoracopulmonary compliance, which requires greater airway pressure to generate a given tidal volume. Patients with forced expiratory volume in one second (FEV_1) < 70% or diffusion capacity < 80% may not be suitable candidates for laparoscopy. Even though Laparoscopic surgery and Co_2 insufflation for pneumoperitoneum is associated with increased Co_2 absorption, changes in arterial co_2($PaCo_2$) remains clinically insignificant in healthy patients. However, in patients with severe pulmonary disease and limited elimination of co_2 this resulting rise in $Paco_2$ may be significant despite aggressive hyperventilation. In these population the end tidal Co_2 ($ETco_2$) may underestimate $PaCo_2$.[3]

Laparoscopic surgery is associated with an increased risk of respiratory complications, such as subcutaneous emphysema, pneumothorax, pneumomediastinum, and pneumopericardium. The most common respiratory complication during laparoscopy is subcutaneous emphysema. Other complications can occur due to the cephalad displacement of the carina, such as endobronchial intubation and gas embolism. These complications can have serious consequences and require prompt recognition and management.

1.1.3. Gastrointestinal effect

Increased incidence of nausea and vomiting.

1.1.4. Renal & metabolic-

During pneumoperitoneum, there is an increase in renal vascular resistance due to the compression of the renal vasculature. This, coupled with a decrease in cardiac output, leads to reduced renal perfusion and an overall decrease in renal clearance. Specifically, there is a 50% reduction in the glomerular filtration rate (GFR) and urine output during pneumoperitoneum. Fortunately, urine output recovers promptly after the release of pneumoperitoneum.

To compensate for the decrease in renal perfusion, the body activates stress hormones such as catecholamines, resulting in an increase in systemic vascular resistance, heart rate, and contractility. Renal autoregulation also stimulates the renin-angiotensin-aldosterone system (RAAS), causing the release of renin and subsequent secretion of aldosterone. Additionally, neuroendocrine responses lead to the excretion of anti-diuretic hormone. As a result, there is salt and water retention with oliguria, creating a vicious cycle of renal cortical vasoconstriction that further activates the RAAS. These compensatory mechanisms exacerbate the decrease in renal perfusion and urine output during pneumoperitoneum.

1.1.5. Neurological

Intra cranial pressure (ICP) is increased (further exacerbated by head down position) which may result in decrease in Cerebral perfusion pressure.

1.2. Physiological effect from absorbed CO_2.

During laparoscopy, CO_2 is commonly used to create a pneumoperitoneum. The absorption of CO_2 from the peritoneal cavity into the bloodstream leads to an increase in blood CO_2 levels, which usually reaches a plateau about 25% above pre-insufflation values after the first 20 minutes of pneumoperitoneum. However, the absorption of CO_2 may be limited by reduced peritoneal perfusion, caused by increased intra-abdominal pressure. As $PaCO_2$ levels increase, the sympathetic nervous system is activated, resulting in hypertension, tachycardia, increased myocardial contractility, and increased catecholamine sensitivity. Patients under controlled ventilation during laparoscopy require a 15-20% increase in minute ventilation to prevent hypercapnia. Postoperatively, patients may experience a higher $PaCO_2$ and a reduction in pH due to increased $PaCO_2$. However, the pH promptly returns to normal after the abdomen is desufflated.

1.3. Physiological effect of positioning

Table 1 Effects on Cardiovascular and Respiratory system relative to position

	Head up position	**Head down position**
Cardiovascular effect:	Venous return and cardiac output are reduced. Mean arterial pressure decreases. Pulmonary vascular resistance increases. Left ventricular end-systolic wall stress increases. Left ventricular end-diastolic area decreases, while left ventricular ejection fraction remains constant.	There is increase in venous return and CO (However, in the presence of a pneumoperitoneum, venous return and CO are overall decreased) Pneumoperitoneum can lead to an increase in pressure within the venous system of the brain and eyes, which may result in complications such as cerebral edema and retinal detachment. This can also cause edema in the face and neck region.
Respiratory changes	Most favorable position.	Facilitates atelectasis. Decreases FRC, overall lung volumes, and lung compliance.

		Patients who are morbidly obese may experience increased airway pressures, which can make it difficult to maintain prolonged Trendelenburg position during laparoscopic procedures. Trendelenburg position during surgery can cause the endotracheal tube to shift and potentially enter one of the patient's bronchi, leading to compromised ventilation. Therefore, it is recommended to monitor the patient's oxygen saturation and listen to both lungs after positioning, as well as be vigilant throughout the procedure, to ensure proper ventilation and prevent any adverse events.

1.4. Intraoperative Complications

Complications related to abdominal access during laparoscopy are not uncommon, with over 50 percent of such complications occurring during this stage in gynecologic laparoscopy.[4] The overall complication rate of laparoscopy is reported to be 5.7 per 1000 procedures, with vascular injury and bowel injury being potential complications. Vascular injury, which can range from 0.1 to 6.4 per 1000 laparoscopies, often occurs during the insertion of a pneumoperitoneum needle or primary trocar.[5]Contrary to previous beliefs, most intestinal injuries during laparoscopy are not caused by electrosurgery but rather by the placement of a pneumoperitoneum needle or trocar. Injury to the gastrointestinal tract is rare, occurring in only 0.03 to 0.18 percent of patients undergoing laparoscopic surgery, with the small bowel being the most commonly affected structure during abdominal access for this type of surgery.[6]

1.4.1. Co_2 embolism

CO_2 embolism is a rare but serious complication that can occur during laparoscopic procedures. It is most commonly seen during the initial insufflation of gas due to accidental insertion of the trocar or Veress needle into a blood vessel or abdominal organ. The severity of CO_2 embolism depends on the volume and speed of the gas that enters the circulation.

During laparoscopic hysterectomy, most of the embolisms occur during round ligament transection and broad ligament dissection.[7] Unlike air embolism, CO_2 embolism does not cause bronchospasm. However, injecting large volumes of gas under pressure can cause an "air lock" in the vena cava or right atrium, resulting in sudden cardiovascular collapse.

It is crucial to closely monitor patients and maintain a high degree of suspicion to detect CO_2 embolism early. Signs of embolism may include tachycardia, arrhythmias, hypotension, millwheel murmur, and EKG signs of right heart strain. Capnography is the most sensitive detector of CO_2 embolism. Transesophageal Echocardiography (TEE) is useful tool in detecting gas embolism.

If CO_2 embolism is suspected, treatment involves stopping insufflation, releasing the pneumoperitoneum immediately, and administering 100% oxygen. Turning the patient's head down on the left side is recommended to prevent gas bubbles from entering the pulmonary artery. Cardiopulmonary resuscitation may be necessary, and aspiration of gas through a central venous pressure (CVP) line may be attempted. In severe cases, cardiopulmonary bypass has been used successfully. Hyperbaric oxygen may also be recommended to treat suspected cerebral embolism.

Additionally, paradoxical embolism may occur through a probe patent foramen ovale or atrial septal defect, leading to cerebral CO_2 embolism.[8]

1.4.2. Pneumothorax, Pneumomediastinum

Pneumothorax and pneumomediastinum are uncommon occurrences during gynecological procedures, with retroperitoneal laparoscopy being the most common procedure associated with them. A congenital defect in the diaphragm may permit peritoneal gas to enter the pleural cavity.

A diagnosis of pneumothorax can be suspected if there is an elevation in peak inspiratory pressure (PIP), reduced oxygen saturation levels (SpO2), and decreased breath sounds on one side of the chest. A chest X-ray should be obtained to confirm the diagnosis, and a decrease in the amplitude of the QRS complex in precordial ECG leads may also suggest the presence of a pneumothorax. The laparoscopist may be able to visualize abnormal movement of one hemidiaphragm. Ultrasound is also an important tool to identify pneumothorax in such situation, which shows absence of the lung sliding and a barcode sign in M mode. Barcode sign is uniformly parallel horizontal lines above and below the pleural lines due to lack of motion in the chest wall or lung.

If the patient displays a decrease in mean arterial pressure (MAP) and SpO_2, it may indicate the presence of a tension pneumothorax, which necessitates immediate decompression. In the absence of a tension pneumothorax, and unless a pulmonary cause such as a ruptured bulla is present, the pneumothorax usually resolves on its own within 30 to 60 minutes after the surgery. If the patient is stable, it is advisable to manage the condition conservatively during surgery. Chest tube drainage should be avoided during surgery to ensure that the pneumoperitoneum is maintained. To maintain oxygenation and complete the surgery, it may be necessary to increase the fraction of inspired oxygen (FiO_2), add 5 cm of positive end-expiratory pressure (PEEP), and decrease the intraabdominal pressure.

1.4.3. Subcutaneous CO_2 emphysema

Subcutaneous emphysema due to CO_2 tracking into tissue planes can occur alone or alongside pneumothorax or pneumomediastinum. An abrupt and significant increase in $ETCO_2$ is a characteristic sign. Managing subcutaneous emphysema requires a higher-than-normal increase in minute ventilation. While it usually resolves on its own over a few hours, there is a rare possibility of needing to halt the surgery or even convert to open surgery if the patient's crepitus and tissue swelling are severe. It's important to monitor the patient post-procedure, as CO_2 absorption can decrease their respiratory drive and require mechanical ventilation until CO_2 levels return to normal. This typically resolves within 24 hours or less, depending on the severity.

1.4.4. Nerve injury

During laparoscopy, patients are placed in the lithotomy position which may pose risks of nerve injuries. Specifically, the common peroneal and sciatic nerves are at risk of damage. In addition, shoulder restraints used to maintain steep head-down positioning may cause pressure or stretching on the brachial plexus leading to injuries. Prolonged head-down positioning can also cause acute venous congestion of the optic canal resulting in optic neuropathy and postoperative blindness.[9] It is important for surgeons and anesthesia providers to be aware of these potential risks and take appropriate measures to prevent nerve injuries and avoid prolonged head-down positioning.

1.4.5. Lower limb Compartment Syndrome

Prolonged laparoscopy performed in the lithotomy position may lead to Lower limb compartment syndrome.

1.4.6. Fluid balance

Patients who have undergone bowel preparation and prolonged fasting may be dehydrated upon arrival in the operating room. Assessing intraoperative blood loss can be challenging due to dilution in large volumes of irrigation fluid. The traditional indicators such as heart rate, central venous pressure, and urine output are unreliable parameters to appropriately assess the blood loss . Urine output may also decrease during laparoscopy, making it an inadequate tool for guiding fluid therapy as it could lead to fluid overload.[2] Instead, dynamic indicators such as stroke volume or pulse pressure variation are preferred. Fluid therapy should be tailored to patient characteristics and the type of surgery performed.[10,11] For major elective surgical procedures, minimizing fluid intake and adopting a goal-directed fluid administration approach is recommended. [12]Careful monitoring of irrigating fluid balance during surgery can help alert the anesthesiologist when significant deficits are accumulating. Absorption of intra-abdominal irrigating fluid can also result in pulmonary edema, leading to dyspnea and hypoxemia in the recovery room.

1.4.7. Heat loss

During laparoscopy, the use of peritoneal gas insufflation and large volumes of peritoneal irrigation can lead to hypothermia, and it should be avoided in all patients, especially in patients with cardiac risk factors who are more susceptible to perioperative myocardial events in the presence of mild hypothermia. Although warming of insufflation gas has not been effective in preventing hypothermia, warming of irrigation fluids and the use of a forced-air warming blanket have been found to be helpful in reducing the incidence of postoperative hypothermia and its associated complications. Therefore, it is important to consider the risks of hypothermia and take appropriate measures to maintain normothermia during laparoscopic procedures.

1.5. Preoperative management

1.5.1. Preoperative Evaluation and Premedication

Before undergoing laparoscopic surgery, patients should undergo a thorough evaluation, particularly those with existing medical conditions. Patients with severe heart disease, especially congestive heart failure, require careful examination since they may not tolerate the cardiovascular changes that occur during laparoscopy. In some cases, an open surgical procedure may be a better option. It is important to note that certain medical conditions, such as raised intracranial pressure or the presence of ventriculoperitoneal or peritoneojugular shunts, are contraindications for laparoscopy.

To ease anxiety before surgery, patients may receive a small dose of the short-acting benzodiazepine midazolam (1-2 mg), which doesn't contribute to postoperative sedation. For patients with a history of severe postoperative nausea and vomiting, transdermal scopolamine is an effective adjunct to antiemetic medication administered during surgery. However, it should be given at least 4 hours before the end of surgery to be effective.

In patients at risk of regurgitation of gastric contents, administering a non-particulate antacid before surgery increases gastric pH. Metoclopramide and H2 receptor blockers may be given to decrease gastric volume and acidity.

1.6. Choice of Anesthesia

Operative gynecologic laparoscopy requires optimal surgical conditions, steep head-down positioning, muscle relaxation, a large pneumoperitoneum, and multiple incisions. General anesthesia is considered the safest and most comfortable choice for this type of procedure. Although the laryngeal mask airway has been used successfully, endotracheal intubation is preferred to protect the airway from aspiration of gastric contents and facilitate increased minute ventilation in the presence of increased airway pressures.

Propofol anesthesia has been associated with better postoperative recovery in outpatient surgery. During mask ventilation after muscle relaxant administration, care must be taken not to inflate the stomach with gas. Once the endotracheal tube is secured, an orogastric tube is passed to decompress the stomach. To keep intra-abdominal pressure as low as possible, controlled ventilation, maintaining muscle relaxation, and a relatively deep plane of anesthesia can be used.

Continuous intraoperative monitoring, including pulse oximetry, ECG, $ETCO_2$, blood pressure, temperature, muscle relaxation, minute ventilation, and airway pressure, is recommended. Patients with cardiac disease may benefit from invasive hemodynamic monitoring.

Regional anesthesia (spinal and epidural) can be considered for shorter laparoscopic procedures such as diagnostic laparoscopy, which requires lower intra-abdominal pressure and minimal head-down tilt. [13,14] However, patient discomfort due to the creation of pneumoperitoneum, extreme position changes, and significant sympathetic denervation associated with adverse respiratory and cardiovascular responses can complicate perioperative management.[15]

1.7. Recovery from Anesthesia

1.7.1. Postoperative Nausea and Vomiting

Postoperative nausea and vomiting (PONV) is a common problem after surgery, and it can be particularly problematic after laparoscopy, with an incidence of around 50%. Patients at highest risk for PONV include younger, nonsmoking women with a history of motion sickness or previous PONV, and those who are at risk of receiving opioids. Because of the high incidence of PONV after laparoscopy, prophylactic antiemetic medication may be warranted. Prompt treatment with antiemetic medications and steroids in the recovery room can help manage PONV. Allowing enough time for the gas to escape before closure can also help reduce the risk of PONV.

1.7.2. Pain Management

Postoperative pain is common in the abdomen, shoulders, and back. Factors that can affect the intensity of pain include the duration of the procedure, the degree of intra-abdominal pressure (IAP), and the volume of residual subdiaphragmatic gas.[16] Shoulder pain, which is caused by diaphragmatic irritation and phrenic nerve stimulation, tends to become more significant on the second postoperative day. Optimal evacuation of the subdiaphragmatic CO_2 gas prior to the wound closure should be done. The instillation of long-acting anesthetics may provide relief for some patients. Intravenous lidocaine infusion during the intraoperative and postoperative periods has been shown to decrease postoperative pain, opioid requirements, and hospital stay duration while also improving bowel function.[17] Local anesthetic techniques, such as infiltration of the abdominal wounds, rectus sheath block, transversus abdominis plane (TAP) block, and ultrasound-guided TAP block, have also been used to reduce postoperative pain.

USG guided TAP block which involves the administration of local anesthetic in between the layers of internal oblique and transverse abdominis muscle is beneficial in reducing post operative pain. [18]. Data specific to gynecological surgery is scarce with conflicting results. [19] Laparoscopic guided TAP has also been described with good results.[20]. In addition, parenteral glucocorticoids have been found to be effective in reducing postoperative pain and length of hospital stay. An intraperitoneal saline infusion can help to decrease postoperative pain and carbon dioxide gas dissolution. A combination of narcotics, local anesthesia, and an NSAID may offer the best relief, although there is evidence of increased postoperative bleeding associated with NSAIDs.

1.8. Pregnancy and laparoscopic surgery.

Laparoscopic surgery, if necessary, should be performed after 1st trimester. The ports should be placed to avoid injury to the gravid uterus. The use of open/Hasson technique for initial port placement is advised. Risk of fetal acidosis can be minimized by maintaining the $ETCO_2$ to 25-35 by changing the minute ventilation.

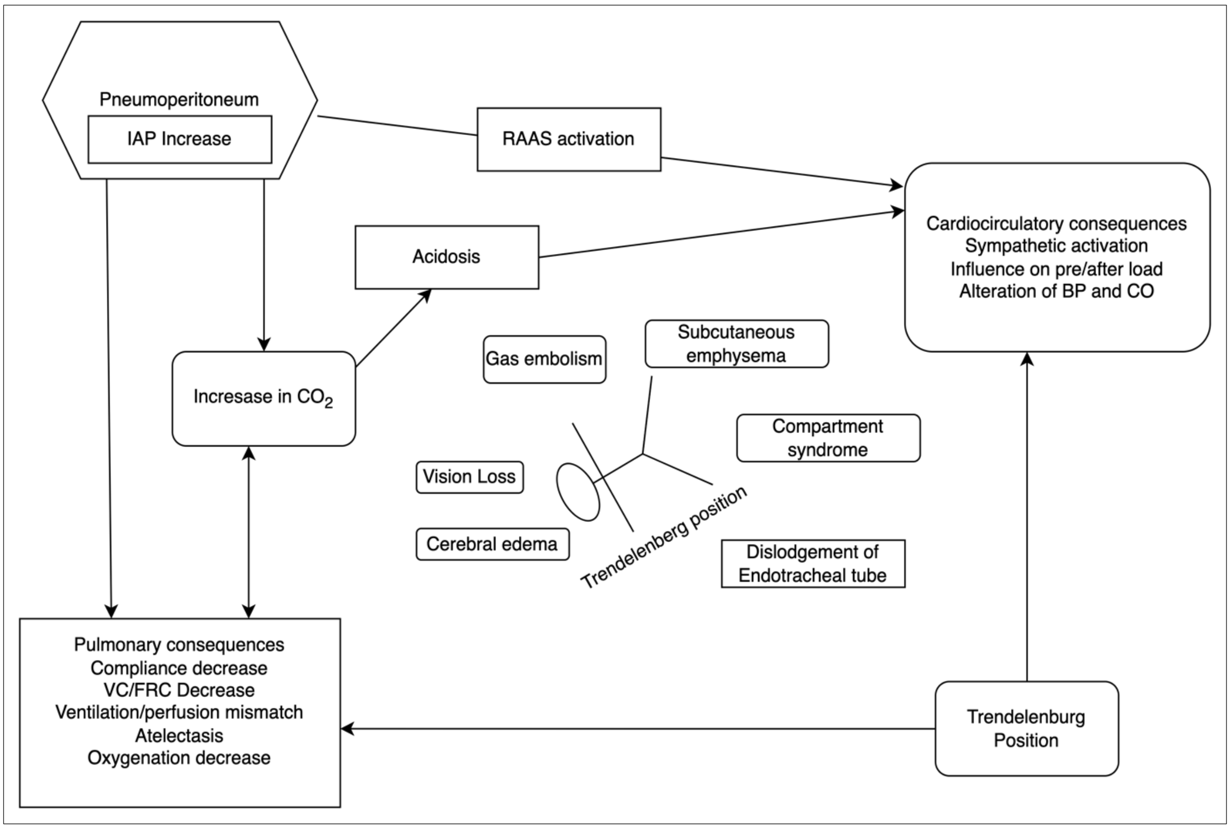

Figure 1 Graphical representation of the effects of Pneumoperitoneum and positioning in Laparoscopic surgery

2. Conclusion

In summary, laparoscopy has become a widely adopted surgical technique in gynecology due to its numerous advantages, such as reduced pain and faster recovery. However, it also poses challenges that may compromise patient safety, such as hemodynamic instability and potential complications such as pneumothorax, air embolism, and hypoxemia. Anesthesiologists play a critical role in managing these challenges by closely monitoring hemodynamics, utilizing appropriate anesthetic techniques, and promptly identifying and addressing potential complications. By continuously improving and refining anesthetic approaches, anesthesiologists can help enhance patient safety and achieve optimal surgical outcomes. Ongoing research in this area is crucial to further advance our understanding of the effects of laparoscopy on hemodynamics and mitigate complications associated with this surgical technique.

Compliance with ethical standards

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Disclosure of conflict of interest

There are no conflicts of interest.

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