Anesthesia in Laparoscopic Surgery

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INTRODUCTION

The anesthetic problems during minimal access surgery are related to the cardiopulmonary effects of pneumoperitoneum, carbon dioxide (CO_2) absorption, extraperitoneal gas insufflation, venous embolism, and inadvertent injuries to intra-abdominal organs. Optimal anesthetic care of patients undergoing laparoscopic surgery is very much important. Good anesthetic techniques facilitate risk-free surgery and allow early detection and reduction of complications.

In young patients, fit for diagnostic laparoscopy, general anesthesia is the preferred method and does not impose any increased risk. Adequate anesthesia and analgesia are essential and endotracheal intubation and controlled ventilation should be considered. The pneumoperitoneum can be created safely under local anesthesia provided that the patient is adequately sedated throughout the procedure. For successful laparoscopy under local anesthesia, intravenous (IV) medication for sedation should be given.

EVALUATION AND PREPARATION OF PATIENT FOR LAPAROSCOPIC SURGERY

A thorough preanesthetic assessment is mandatory and all comorbidities should be optimized in case the procedure needs to be converted to an open one. Premedication should include a short-acting anxiolytic, an H_2-receptor antagonist, and an analgesic for preemptive analgesia.

Many of the patients scheduled to undergo laparoscopic surgery are young women undergoing gynecological laparoscopy. Young women undergoing gynecological procedures under general anesthesia are at high risk of postoperative nausea and vomiting. Laparoscopy itself is also associated with postoperative nausea and vomiting, probably due to stretching of the abdominal cavity or residual irritant effects of retained CO_2. Anesthesiologists should plan their anesthetic to prevent and treat postoperative nausea and vomiting in these patients.

A second group of patients that cause concern are those with significant cardiac disease. Most of these patients tolerate abdominal insufflation at low pressures currently used (<18 mm Hg) surprisingly well. If the operation is to be of short duration, few patients with cardiac disease, other than those with severe congestive heart failure, require invasive monitoring. However, insufflation can be associated with a moderately reduced cardiac index, increased cardiac filling pressures, systemic blood pressure, and systemic vascular resistance. In addition, hypercarbia from insufflated CO_2 may be detrimental to patients with cardiac disease by stimulating the sympathetic nervous system and vasopressin release. Therefore, for extensive laparoscopic procedures, direct arterial and pulmonary artery catheterization and/or transesophageal echocardiography may be necessary for monitoring.

A third group of patients of concern are those with severe emphysema, asthma, cystic fibrosis, or other pulmonary disease. Often, these are patients who would benefit from a laparoscopic operation as opposed to an open procedure because of improved postoperative pulmonary function following procedures performed laparoscopically. However, some of these patients may not be able to be adequately ventilated to eliminate the CO_2 absorbed during laparoscopy. It is important for patients with severe lung disease to be in optimum medical condition prior to having surgery.

The anesthesiologist must be certain that the patient does not have an upper respiratory tract infection or other conditions that may impair pulmonary function at the time of surgery. Prior preparation with a course of bronchodilators, steroids, and/or antibiotics may be necessary. In these patients, an intra-arterial catheter for arterial blood sampling for gas analysis as well as direct arterial pressure monitoring is essential, since the end-tidal carbon dioxide ($EtCO_2$) tension often does not accurately reflect the arterial CO_2 tension and may be significantly lower.

Laparoscopic procedures offer numerous advantages in obese patients including less postoperative pain, pneumonia and wound site infection, better respiratory functions and cosmetic appearance, shorter duration of recovery and discharge, and lower total cost. Full understanding of pathophysiological changes is necessary for an optimal anesthetic care. These patients are at risk of other comorbidities such as hypertension, diabetes mellitus, cardiac problems, and respiratory problems and should be thoroughly examined and managed before planning for surgery. Thromboprophylaxis is essential in the morbidly obese patients scheduled for bariatric surgery. Low-molecular-weight heparin, enoxaparin 0.6 mL subcutaneous (SC), dalteparin 5,000 IU SC, or fondaparinux 2.5 mg SC is given 12 hours before surgery. Mechanical thromboprophylaxis with sequential compression devices is mandatory.

A laparoscopic surgeon should develop communication and understanding with his anesthetist. Adequate preoperative assessment of the patient and the disease minimizes the risk of general anesthesia. Necessary measures should be undertaken to correct any metabolic or hematological abnormalities such as hypokalemia, hyponatremia, hyperglycemia, azotemia, anemia, and coagulation defects. All the required preanesthetic laboratory data should be available including blood grouping and testing for the hepatitis B antigen and human immunodeficiency virus (HIV). Patients should have an electrocardiogram and chest X-ray.

PHYSIOLOGICAL CHANGES DURING LAPAROSCOPY

The introduction of gas into the peritoneal cavity under pressure may cause pain, respiratory distress, and possibly cardiac embarrassment. Further, Trendelenburg position is necessary for access but extreme Trendelenburg position enhances respiratory and cardiac embarrassment.

Pneumoperitoneum at the time of laparoscopic surgery causes upward displacement of the diaphragm, resulting in the reduction in lung volumes including functional residual capacity (FRC). Pulmonary compliance is reduced and airway resistance is increased due to high intra-abdominal pressure (IAP). The anesthetist often uses high airway pressure to overcome the IAP for a given tidal volume, which increases the risk of hemodynamic changes and barotraumas.

The impaired diaphragmatic mobility gives rise to uneven distribution of ventilation to the nondependent part of the lung, resulting in ventilation-perfusion (V/Q) mismatch with hypercarbia and hypoxemia. The ventilatory impairment is even more severe if there is associated airway and alveolar collapse. Increased IAP also predisposes to regurgitation of gastric contents and pulmonary aspiration.

Insufflation of CO_2 is usually accompanied by hypercapnia. The reason initially proposed to explain this hypercapnia was that CO_2 was reabsorbed from the peritoneal cavity. This explanation was all the more plausible in that it was based on the capacity of CO_2 to diffuse and the exchange capacities of the peritoneal serosa. Recent studies reveal a two-phase phenomenon, with absorption proportional to intraperitoneal pressure for low insufflation pressures, then a drop in the rate of this reabsorption probably due to the peritoneal circulation being crushed under the effect of the pressure. The variations in arterial partial pressure of carbon dioxide ($PaCO_2$) observed during the second phase with high IAPs which act against reabsorption essentially depend on a change in the V/Q ratio with an increase in the dead space.

The hypercapnia mechanism is different with extraperitoneal insufflation. In this case, the pressure effect limiting reabsorption from the peritoneum no longer applies. The increase in pressure increases the diffusion space by dilacerations of the tissues and thus the CO_2 reabsorption surface. Reabsorption is thus directly proportional to the pressure and volume of CO_2 insufflated in extraperitoneal insufflation. Severe hypercapnia is thus possible, if not to say frequent, in these situations. On the other hand, provided the hypercapnia is controlled, the circulatory effect of extraperitoneal insufflation is lower than those of intraperitoneal insufflation.

The increase in intrathoracic pressures induced by the increase in IAP can be limiting factors for laparoscopic surgery in certain patients. Insufflation of the pneumoperitoneum in laparoscopic surgery is accompanied by a decrease of some 30% in pulmonary compliance. The resistance of the air passages increases in the same proportions. The resulting increase in pressure in the air passages can have adverse consequences for patients with bubbles of emphysema. These patients and all those who suffer from dystrophy of the pulmonary parenchyma will find it difficult to cope with the often considerable hyperventilation required by hypercapnia, with volumes per minute sometimes reaching two or three times than normal.

Venous gas embolism is a fatal complication of pneumoperitoneum. Veress needle or the trocar may directly puncture the arteries or blood flow across an opening in an injured vessel, may sometimes draw gas into the vessel and leads to gas embolism.

A slow infusion of air <1 L/min is absorbed across the pulmonary capillary-alveolar membranes without causing any damage. At higher infusion rates, the gas bubbles lodging in the peripheral pulmonary arterioles provoke neutrophil clumping, activation of the coagulation cascade, and platelet aggregation. This may lead to pulmonary vasoconstriction, bronchospasm, pulmonary edema, and pulmonary hemorrhage. Gas bubbles attached to fibrin deposits and platelet aggregates mechanically obstruct the pulmonary vasculature and increases the pulmonary vascular resistance.

The increased right heart afterload leads to acute right heart failure with arrhythmia, ischemia, hypotension, and elevated central venous pressure. Sometimes, paradoxical embolism is seen through a patent foramen ovale.

Elevated IAP produces physiological changes in the hemodynamic by its effects on systemic vascular resistance, venous return, and myocardial performance. Systemic venous return increases when IAP is elevated. Effects on venous return and cardiac output depend on the magnitude of the IAP. Venous return initially increases with IAP below 10 mm Hg. This paradox is due to reduction in the blood volume sequestrated in the splanchnic vasculature which increases cardiac output and arterial pressure. When IAP exceeds 20 mm Hg, the inferior vena cava is compressed. Venous return from the lower half of the body is impeded resulting in a fall in cardiac output.

A number of animal studies have been devoted to variations in cardiac output induced by the increase in intraperitoneal pressure. The results are consistent with a fall in cardiac output proportional to the intraperitoneal pressure. In low abdominal pressure (5 mm Hg), cardiac output remains unchanged. The drop in right transmural auricular pressure indicates a reduction in the venous return which is demonstrated by a reduction in flow, through the vena cava, the degree of which is proportional to the intra-abdominal pressure.

The cardiac output is governed by the myocardial function, the postloading, and by the venous return, the latter in turn depending on venous resistance and mean systemic pressure. With an IAP of 5 mm Hg, the venous return improves. Under these conditions, the intraperitoneal pressure remains lower than the pressure in the vena cava which results in a flushing effect, with no obstructive phenomena in the lower vena cava. When the intraperitoneal pressure rises above the intravascular pressure, a subdiaphragmatic narrowing of the lower vena cava slows the flow of blood. The abdominal blood volume is reduced due to the pressure and a reflux into the venous system of the lower limb occurs.

The increase in vascular resistance can be explained by the splanchnic vascular compression, but the persistence of high resistance after exsufflation, means a humoral factor could be suggested. During the increase in intraperitoneal pressure, a considerable rise in antidiuretic hormone is found and its vasopressive effects are well-known. This secretion would seem to be dependent on the drop in cardiac flow rate. A simultaneous rise in the level of plasma norepinephrine, whose vasoconstrictor effects are equivalent to those of vasopressin, has also been reported. The increase in vascular resistance is correlated with a rise in arterial pressure in so far as inotropism is sufficient.

The circulation of kidney becomes much compromised with increased IAP. Renal blood flow and glomerular filtration rate decrease because of increase in renal vascular resistance, reduction in glomerular filtration gradient, and decrease in cardiac output. The increase in systemic vascular resistance impairs left ventricular function and cardiac output. Arterial pressure, however, remains relatively unchanged, which conceals the fall in cardiac output. High intrathoracic pressure during intermittent positive pressure ventilation adds in impairment of venous return and cardiac output, particularly if positive end-expiratory pressure (PEEP) is also applied. The elevation in IAP produces lactic acidosis, probably by severely lowering cardiac output and by impairing hepatic clearance of blood lactate.

Stretching of the peritoneum sometimes leads to stimulation of vagus nerve and can provoke arrhythmias such as atrioventricular dissociation, nodal rhythm, sinus bradycardia, and asystole. This shock is more commonly seen with rapid stretching of the peritoneum at the beginning of peritoneal insufflation.

Faulty pneumoperitoneum may give rise to subcutaneous emphysema, pneumomediastinum, pneumopericardium, and pneumothorax. However, gas can also dissect through existing defects in the diaphragm or along surgically traumatized tissue planes in the retroperitoneum, the diaphragm, or the falciform ligament. Gas can leak into the subcutaneous tissues connected with poor positioning of a trocar sleeve (2.7% of cases of severe hypercapnia in a series of cholecystectomies published by Wieden); CO_2 is seen to spread outside the abdominal cavity during laparoscopic-assisted hysterectomy, with or without lymphadenectomy and during bladder neck suspensions. In laparoscopic gynecological surgery, because this effusion originates in the pelvis, it mostly affects the sides and loins and generally remains hidden by the drapes until the end of the operation. Only the very abundant, rare forms can be diagnosed by the anesthetist during the operation, when they shift toward to the upper part of the thorax. In this case, the capnographic signs (slow and regular increase in CO_2 expired) will provide an alert during the anesthesia.

Major factors that alter physiology during laparoscopic surgeries are:

- Pneumoperitoneum
- Carbon dioxide
- Positioning

Effects of reverse Trendelenburg position during laparoscopy are:

- Decreased preload
- Decreased mean arterial pressure
- Blood pooling to lower extremities leading to increased risk of venous thromboembolism
- Improved pulmonary functions

Effects of Trendelenburg position during laparoscopy are:

- *Respiratory*:
    - Decreased vital capacity
    - Decreased FRC
    - Abdominal contents restrict movement of diaphragm
    - Decreased compliance
    - Increased V/Q abnormalities
- *Circulatory*: The changes seen in healthy patients are minimal and consist of increased venous return and

cardiac output. The changes are more severe in patients with cardiovascular comorbidities and can be seen as increased central venous pressure and pulmonary artery occlusion pressure with decrease in cardiac output. There may be increase venous return and myocardial oxygen (O_2) demand leading to acute heart failure.

Pneumoperitoneum may lead to vagally-mediated reflexes such as bronchospasm, bradycardia, and sinus arrest. This is seen especially in young women when CO_2 insufflation is done rapidly. Similarly, cardiovascular collapse and gas emboli may also be seen.

Carbon dioxide stimulates sympathoadrenal system and may lead to increase cardiac output, heart rate, blood pressure, and force myocardial contraction. It increases cerebral blood flow and intracranial pressure. In neuroendocrine system, it increases epinephrine, norepinephrine, renin, cortisol, aldosterone, and antidiuretic hormone. It causes direct vasodilation of the splanchnic capillary beds whereas causes oliguria and decrease in glomerular filtration rate.

GENERAL ANESTHESIA

General anesthesia with tracheal intubation and controlled ventilation is recommended. This provides optimal control of CO_2, facilitates surgical access, and protects against aspiration of gastric contents.

Traditional volume controlled ventilation ensures an adequate tidal volume, but there is an increased risk of high inflation pressures and barotrauma, especially in bariatric surgery for the morbidly obese. Use of pressure controlled ventilation minimizes peak pressure and improves oxygenation in such situations.

Anesthesia for laparoscopy can be achieved with a variety of agents and techniques. General anesthesia using balanced anesthesia technique including IV induction agents such as thiopentone, propofol, etomidate, and inhalational agents like isoflurane, desflurane, and sevoflurane can be used **(Fig. 1)**. An ideal general anesthesia machine should have:

- Spontaneous breathing with computerized ventilation
- Manual ventilation
- Volume controlled ventilation
- Pressure controlled ventilation
- Computerized pressure support

Muscle relaxation can be done with atracurium, cisatracurium, vecuronium, and rocuronium. Pain can be controlled with opioids such as fentanyl and remifentanil along with nonopioid adjuvants such as paracetamol and dexmedetomidine.

Few anesthetist advocates use of laryngeal mask airways (LMAs), which avoid the postintubations or throat and laryngeal sequelae, but this is associated with a risk of inhalation of gastric content and gastric distension. However, the ProSeal LMA has been found to be as effective as a tracheal tube for pulmonary ventilation in laparoscopic surgery.

REGIONAL ANESTHESIA

Spinal anesthesia is reported enthusiastically for diagnostic laparoscopy without significant complications. Regional anesthesia may be useful for pelvic procedures but if high block is used it interferes with the respiratory status of patient. Bilateral lower intercostal nerve block has also been used, but it is time-consuming and it can cause pneumothorax.

Table 1 shows the comparison of general and regional anesthesia for laparoscopy.

Fig. 1: Ideal anesthesia machine.

TABLE 1: Comparison of general and regional anesthesia for laparoscopy.

	Advantages	*Disadvantages*
Regional anesthesia	• Avoids use of different drugs • Awake and spontaneously breathing patient • Faster recovery and ambulation • Less postoperative pain • No airway manipulation • Decreased PONV	• Significant hypotension • Shoulder discomfort due to diaphragmatic irritation • Patient anxiety • Risk of postoperative urinary retention • Risk of hypoventilation and desaturation, if supplemented with sedation • High level of block is required
General anesthesia	• Respiratory changes are well tolerated • Risk of aspiration minimal to nil	• Delayed recovery (especialy in old, obese, and compromised patients) • More postoperative pain • Increased PONV

(PONV: postoperative nausea and vomiting)

LOCAL ANESTHESIA

Many surgeons have done sufficient number of laparoscopic procedures under local anesthesia with IV sedation and results are encouraging with minimal morbidity and negligible mortality. Laparoscopy under local anesthesia should be performed with an anesthetist being present to monitor the patient's cardiac and respiratory functions. IV sedation should be administered with IV diazepam and pethidine. Preferred local anesthetic agent is 1% lignocaine without adrenaline or lidocaine without epinephrine. The anesthetic agent should be administered at the sites of insertion of the needle and all trocars.

If local anesthesia is used, anesthetist should perform valuable service by providing "vocal local technique". Anesthetist should talk constantly to the patient that everything is going well. One of the most difficult situations of local anesthesia is that the patient, rather than the surgeon, becomes the center of attraction for all noises and comments made in the room during surgery.

It is important to understand that under local anesthesia, adequate sedation and analgesia are administered to keep the patient somnolent but responsive. Continuous monitoring of all the vitals is essential throughout the procedure. Secondly, it is essential that a pneumoperitoneum of approximately 1.5–3 L be present under pressure.

ANESTHETIST'S ROLE IN LAPAROSCOPY

The role of anesthetist in laparoscopic surgery is vital. The laparoscopic surgery should never be performed if anesthetist has no experience in minimal access surgical anesthesia. It is up to anesthetist to identify whether he is capable of performing realistically without compromising the safety of the patients. It is only on these clearly established bases that safe laparoscopy can be contemplated.

Pregnant Women

Pregnant women undergoing laparoscopic surgery present several challenges to the anesthesiologist. The effect of carboperitoneum and increased IAP on the uteroplacental blood flow and its overall effect on the well-being of the fetus are the main concerns. In addition, space constraint, trocar insertion, and surgical manipulation are compounding factors. The gravid uterus pressing on the diaphragm leads to further decrease in FRC, increase in V/Q mismatch, and an increase in the arterioalveolar gradient. Special considerations in such patients include placing the patient in left lateral decubitus position, using open Hasson technique for gaining access to the abdominal cavity, maintaining the IAP as low as possible and continuously monitoring the maternal $EtCO_2$.

Fast-track Laparoscopic Bariatric Surgery

Target control infusions of remifentanil and propofol, maintenance with bispectral index (BIS)-titrated desflurane, multimodal analgesia, and antiemetic prophylaxis result in a successful and safe "short-stay" bariatric surgery program.

Pheochromocytoma

Low IAP (<10 mm Hg) along with slow insufflation of CO_2 and gradual positioning of the patient has been found to produce minimal changes in catecholamine levels and hemodynamics and is therefore recommended.

Pediatric

The physiological effects of laparoscopy in children are similar to adults, but the effects of the pneumoperitoneum and the extremes of patient position (Trendelenburg or reverse Trendelenburg) are more profound in neonates and infants. To minimize the negative physiological effects of pneumoperitoneum, it is recommended to have a slower rate of gas insufflation (1 L/min) and a lower IAP (6–8 cmH_2O in infants and up to 12 cmH_2O in older children). Induction of anesthesia can be performed safely using either IV or inhalational techniques. Children are generally more prone to intraoperative hypothermia than adults. In laparoscopic surgeries, the core temperature can drop further if the insufflation gas is cold. Temperature monitoring must be done routinely and patient warming measures such as fluid warming system and cutaneous warming measures should be used to prevent hypothermia.

Thoracoscopy

Initially these procedures were conducted with local anesthetic injected at the point of entry or under intercostal block. This often resulted in hypoxia and hypercarbia due to the pneumothorax. Thoracoscopic surgery is now traditionally done under general anesthesia and one-lung ventilation.

PATIENT SELECTION

- Patients with cardiac pathology must be subjected to a thorough preoperative assessment taking the particular hemodynamic conditions imposed by laparoscopic surgery into account.
- Patients presenting with decompensated congestive cardiomyopathy are at highest risk of laparoscopic surgery because the hemodynamic repercussions would be too difficult to manage, even with the help of invasive monitoring techniques.
- The increase in systemic vascular resistance and the O_2 requirements of the myocardium could be the risk factor in cardiac patients. For these patients, the postoperative benefits of laparoscopic surgery must be weighed against

the intraoperative risks. Preoperative investigation in these patients enables this risk to be evaluated more closely. The cardiac reserve must be assessed carefully; in particular, myocardial contractility and the ejection fraction should be estimated.

- The drop in venous return during peritoneal insufflation is one of the important factors which are responsible for drop in cardiac output during laparoscopic surgery. This drop in venous return is more important when the hypovolemia develops due to excessive bleeding, indicating that hypovolemia is a contraindication, at least for as long as their circulating volume has not been restored to normal. This point is particularly important for ruptured ectopic pregnancy or during laparoscopic surgical exploration of abdominal injuries.

MONITORING

Careful monitoring of a patient undergoing laparoscopic surgical procedure is very important. The American Society of Anesthesiologists (ASA) standard monitoring is mandatory for all patients. A multiparameter monitor **(Fig. 2)** is essential. Peak and plateau airway pressure can be measured from the anesthesia machine. An intra-arterial blood pressure (IBP), cardiac filling pressures, and frequent blood gas monitoring are indicated in high-risk patients undergoing major surgery.

- Electrocardiogram (ECG)
- Rate of respiration
- Pulse oximetry
- Noninvasive blood pressure (NIBP)
- Temperature
- End-tidal carbon dioxide
- Intraperitoneal pressure

Routine Monitoring

The stethoscope remains an important instrument enabling anesthetist to auscultate both the lungs after any change in position and after insufflation of the pneumoperitoneum because it pushes back the tracheal carina, can displace intubation to the right. The use of a stethoscope in the precordial position is a good practice in order to detect gas embolism, but requires permanent auscultation.

Electrocardioscopic monitoring during laparoscopy enables arrhythmia, which may occur due to hypercapnia, to be rapidly detected. At the time of laparoscopic surgery, sudden appearance of a microvoltage can be the sign of subcutaneous emphysema or pneumomediastinum.

Oximetry monitoring [peripheral oxygen saturation (SpO_2)] is essential part of any surgery, but it is especially important in laparoscopic surgery because the dim lighting in the laparoscopic surgery theater and the wearing of protective glasses, if a laser is being used, make it difficult to recognize cyanosis. In any case, the latter is a late clinical sign of hypoxia. Variations in saturation are not specific during laparoscopic surgery. Desaturation is a late sign of complications such as gas embolism, pneumothorax, selective intubation, or a shunt effect due to excessively high intraperitoneal pressure.

During laparoscopic surgery, control of intraperitoneal pressure is an integral part of the anesthesia monitoring. The insufflator must be microprocessor controlled; it must be reliable and subjected to regular checks. Excessive intraperitoneal pressure must trigger an alert and an immediate halt in insufflation. As the majority of older insufflators do not have safety valve for a reduction in intraperitoneal pressure, this must be carried out by manual exsufflation via opening the valve of cannula.

Monitoring of the neuromuscular block is also important. Proper relaxation is good for laparoscopic surgery. Stable and deep myoresolution improves the laparoscopic surgeon's view and limits the peritoneal insufflation pressures. In addition, the wide range of operating times and the rapidity with which an operation is terminated means it is essential to know exactly what the neuromuscular block situation is at any point in time. When equipment for reading the muscular activity in the thumb is not available, the simplest stimulation is a train-of-four on a temporal branch of the facial nerve and observation of the contraction of the orbicular eye muscle.

Intraperitoneal insufflation of dry and unheated gas, possibly accompanied by irrigation with cold liquids, results in heat loss during laparoscopic surgery which is at least equal to that with laparotomy. Temperature monitoring associated with measures to combat heat loss is also essential when procedures take several hours. It is important to remember that excessive leakage of gas through the cannula causes rapid hypothermia to the patient.

Fig. 2: Multiparameter monitor.

Cardiovascular Monitoring

Measurement via the bloodstream enables arterial pressure to be monitored in real time. In addition, the appearance of cyclic variations in time with ventilation is an excellent indication of drops in preloading which prompt the intraperitoneal insufflation pressure to be limited, to increase filling, or even to accentuate the Trendelenburg position when possible. Installation of an arterial entry point also helps with blood gas measurements.

Measurement of central venous pressure is traditionally used to supervise the filling pressures in the right heart. This becomes difficult during laparoscopic surgery because of the changes in position which require continual changes at cell level and particularly because of the increase in intrathoracic pressure transmitted from the peritoneal area via the diaphragm. It is important to perform simultaneous measurement of intrathoracic pressure which is obtained by esophageal pressure and to deduct this from the measured central venous pressure.

Catheterization of the right heart using a Swan-Ganz probe has been used for monitoring during laparoscopic surgery **(Fig. 3)**. As for central venous pressure, the values measured need to be corrected according to the intrathoracic pressure. An increase in pulmonary arterial pressure is an early sign of gas embolism. Aspiration of the gas bubbles by the proximal orifice placed in the right atrium theoretically helps to minimize the consequences of air embolism. The use of a Swan-Ganz probe during laparoscopy for patients with coronary disease helps adapt the anesthesia protocol and therapy, for simple measurement of arterial pressure is insufficient in 80% of these cases. Nevertheless in the course of general anesthesia with controlled ventilation when arterial oxygen saturation (SaO_2), hemoglobin, and O_2 consumption are stable, a change in venous oxygen saturation (SvO_2) is often the sign of a change in cardiac flow rate.

Because right heart catheterization is an invasive procedure, several studies have reported the use of cardiac flow rate monitoring by electrical bioimpedance during laparoscopic surgery. The principle is founded on continuous measurement of the blood flow rate in the thorax by analysis of the variations in conductivity relative to an electrical field. Transthoracic electrical bioimpedance brings a certain number of advantages:

- Low risk (noninvasive monitoring)
- Easy and simple to use
- Continuous measurement in real time
- Not limited in time
- Inexpensive
- Reliability seems to be satisfactory as compared to other methods.

It is important that the skin be carefully prepared and the electrodes are of good quality and correctly positioned.

However, its use in standard monitoring is still limited due in large part to the frequent difficulties encountered in interpreting the variations.

Some studies have been made of hemodynamic monitoring during laparoscopic surgery using trans-esophageal ultrasound cardiography. Whereas the advantages of this technique for monitoring and diagnosis are considerable, the cost remains an important barrier. Interpretation can also be difficult because of the variations in the viewing axis of the heart according to peritoneal pressure and the variable patient's position.

Measurement of the cardiac flow rate by pulsed Doppler velocimetry can be carried out by either the transesophageal or the suprasternum route at the time of laparoscopic surgery. The basic principle is the same as with any Doppler device with a piezoelectric transducer transmitter and a transducer

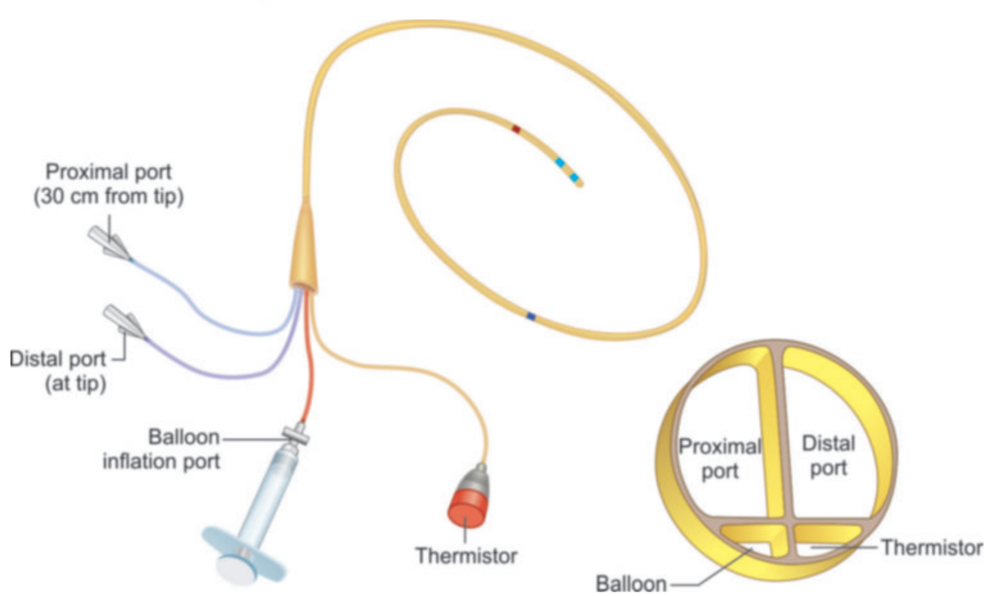


Fig. 3: Swan-Ganz catheter.

receiver which receives the return echoes modified by the Doppler effect when they bounce off mobile structures such as wall of the heart, vessels, or red blood cells. Based on the effective diameter of the aorta which can either be calculated from the cardiac flow rate measured by another method or estimated from the patient's biometric factors, the ejection volume can be deduced and thus the continuous cardiac flow rate.

Respiratory Monitoring

Quantitative waveform capnography is the continuous, noninvasive measurement and graphical display of end-tidal carbon dioxide [$EtCO_2$, also called end-tidal carbon dioxide pressure ($PetCO_2$)]. Capnography uses a sample chamber/sensor placed for optimum evaluation of expired CO_2 **(Fig. 4)**. The inhaled and exhaled CO_2 is graphically displayed on a capnograph as a waveform on the monitor along with its corresponding numerical measurement.

As an assessment tool during laparoscopic surgery, capnography can help the anesthetist determine a number of things. It is a direct measurement of ventilation in the lungs, CO_2 absorption causing hypercarbia, and it also indirectly measures metabolism and circulation. For example, an increase in CO_2 absorption during laparoscopy will increase the $EtCO_2$ and a decrease in perfusion will lower the delivery of CO_2 to the lungs. This will cause a decrease in the $EtCO_2$ and this will be observable on the waveform as well as with the numerical measurement. Capnography is a continuous and noninvasive method for CO_2 measurement and it has become the standard of care for basic respiratory monitoring for intubated patients during laparoscopic surgery. The $PetCO_2$ provides evidence of production of CO_2 by the cellular metabolism, absorbed through the peritoneal cavity and pulmonary exchanges **(Figs. 5A and B)**. A rapid increase in $PetCO_2$ is a serious complication. Thus, continuous and careful monitoring of $EtCO_2$ by capnography is a useful and effective noninvasive monitoring technique in anesthesia for laparoscopy. The $EtCO_2$ immediately reflects changes in circulatory status and ventilation as well as detects complications related to CO_2 pneumoperitoneum (hypercarbia, subcutaneous emphysema, gas embolism, pneumothorax, etc.). Thus, $EtCO_2$ monitoring is mandatory and essential monitoring during laparoscopic surgery for the safe conduct of general anesthesia.

- A rapid rise of a few millimeters of mercury returning a few minutes later to the base figures may be the sign of minimal CO_2 gas embolism.
- A more gradual and persistent rise is often the sign of extraperitoneal diffusion of CO_2 (preperitoneal, subcutaneous, retroperitoneal, mediastinal, etc.). This increase in expired CO_2 continues after exsufflation of the pneumoperitoneum, indeed often several hours after the laparoscopic procedure, justifying a follow-up of hypercapnia in the recovery room.
- The CO_2 is transported by the circulatory system from the peripheral areas toward the lungs. Any disturbance in the circulation will reduce the CO_2 expired. A rapid drop in $PetCO_2$ may be the sign of a drop in cardiac flow rate or a decreased venous return, but also pulmonary arterial obliteration. This is what happens in massive gas embolism which shows up as a drop in $PetCO_2$ proportional in size and duration to the volume of the CO_2 embolus.

Classically, the $PetCO_2$ values are 2–6 mm Hg lower than $PaCO_2$. During anesthesia with artificial ventilation, the V/Q ratio often >1, so a $PaCO_2$-$PetCO_2$ gradient of 10–15 mm Hg must be expected. However, during laparoscopic surgery, the change in the arterial CO_2-$EtCO_2$ gradient is very variable.

Changes in position such as the Trendelenburg or the lateral reclined position can modify the value of the $PetCO_2$. Furthermore, it is shown that in cases of cardiovascular

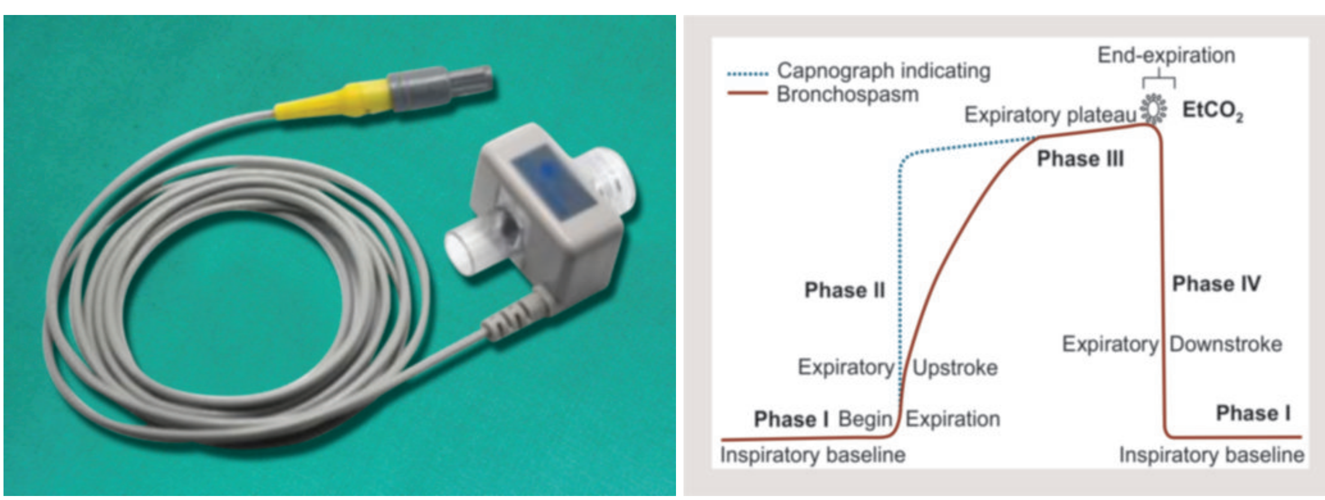
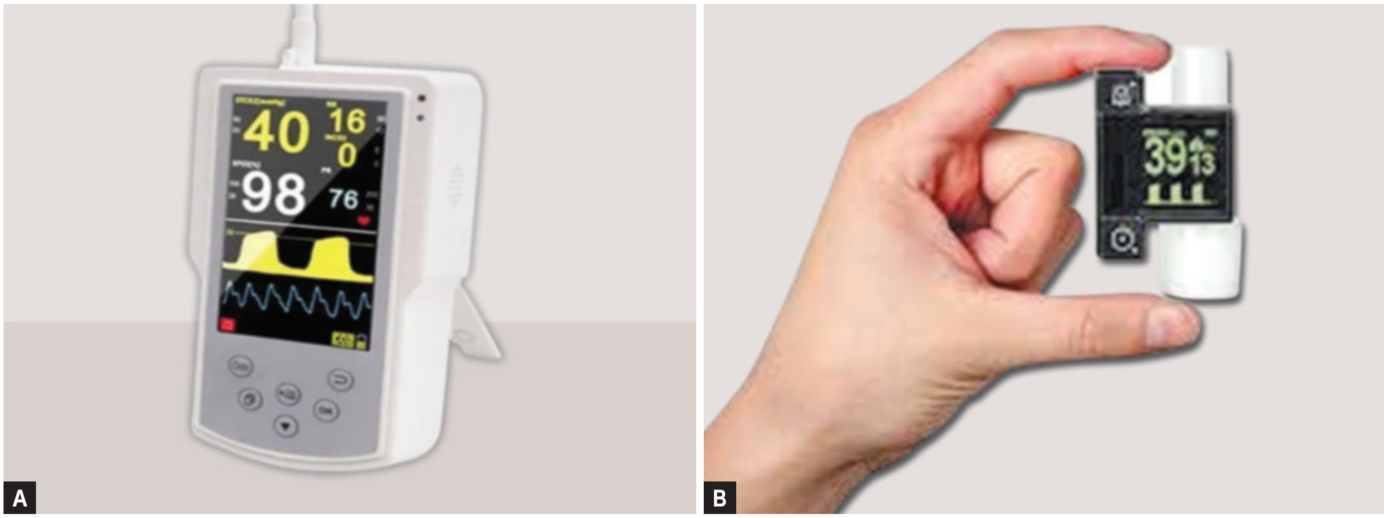


Fig. 4: Capnograph.
($EtCO_2$: end-tidal carbon dioxide)



Figs. 5A and B: Portable carbon dioxide (CO_2) monitor.

disease, the correlation between $PetCO_2$ and $PaCO_2$ was less good when compared with patients with no such pathology and the same is true with obese patients. A recent study confirms that in patients with respiratory impairment, the increase in $PaCO_2$ is underestimated by $PetCO_2$. So, for these patients with respiratory or heart pathology, it is particularly useful to duplicate the $PetCO_2$ measurement by arterial gasometry at the beginning of the operation and every time there is an important variation in $PetCO_2$.

In view of this uncertainty, transcutaneous CO_2 monitoring would give a better idea of $PaCO_2$, but this also raises a certain number of technical problems (heating of electrodes, difficulties with measurements in adults, etc.).

Anesthetist should keep following points in mind at the time of laparoscopic surgery:

- The patient voids urine just prior to entering the operating room.
- No shaving is necessary.
- All patients undergoing laparoscopy should have an empty bowel. In the unlikely event of bowel damage, there is much less risk of contamination if the bowel is empty.
- The position of leg is important considering different laparoscopic procedures. Pressure stocking prevents deep vein thrombosis (DVT).
- Good muscle relaxation reduces the IAP required for adequate working room in abdominal cavity.
- The inflation of stomach should be avoided during artificial ventilation using mask as this increases the risk of gastric injury during trocar insertion or instrumentation.
- The distended stomach also hampers the visibility of Calot's triangle at the time of laparoscopic cholecystectomy or laparoscopic bile duct surgery.
- Tracheal intubation and intermittent positive pressure ventilation should be routinely used. This ensures airway protection and controls pulmonary ventilation to avoid hypocarbia.
- The ventilatory pattern should be adjusted according to respiratory and hemodynamic performance of the individual patient.
- Ventilation with large tidal volumes (12–15 mL/kg) prevents alveolar atelectasis and hypoxemia and allows adequate alveolar ventilation and CO_2 elimination.
- Halothane increases the incidence of arrhythmia during laparoscopic surgery, especially in the presence of hypercarbia.
- Isoflurane is the preferred volatile anesthetic agent in minimal access surgery as it has less arrhythmogenic and myocardial depressant effects.
- Patients should receive adequate airway humidification and protection against unintentional hypothermia because generally the duration of operation is more in laparoscopic surgery.
- Excessive IV sedation should be avoided because it diminishes airway reflexes against pulmonary aspiration in the event of regurgitation.
- Monitoring of $PetCO_2$ is mandatory during laparoscopic surgery. The continuous monitoring of $PetCO_2$ allows adjustment of the minute ventilation to maintain normal concentration of CO_2 and O_2.
- Airway pressure monitor is mandatory for anesthetized patients receiving intermittent positive pressure ventilation.

INTRAOPERATIVE COMPLICATIONS

If anesthetic consideration is not taken properly, arrhythmias have been associated with laparoscopy. The most common are junctional rhythms, bigeminy, and asystole. Bradycardia has been reported due to rapid insufflation, especially in older patients. The increasing pressure on the peritoneum increases vagal tone and bradycardia may develop. This bradycardia may be increased secondary to absorption of CO_2. Atropine has proven effective in restoring vagal tone.

The development of a CO_2 gas embolus is a rarely encountered emergency. It develops due to intravasations of CO_2 used in laparoscopic surgery. Some apparent signs of air embolism include a sudden drop in $EtCO_2$, a drop in blood pressure, and development of an arrhythmia. A classic "waterwheel" or "millwheel" murmur will be heard in cardiac auscultatory area. Should such an event be suspected, further insufflation should be immediately stopped and abdomen should be deflated. The patient should be turned toward left and head-down to deviate the bubbles of CO_2 away from heart. The patient should be hyperventilated with 100% O_2. If a central line is present, aspiration of the embolus should be attempted.

Pulmonary edema can result from aggressive fluid replacement or irrigating fluid absorption. Fluid management is even more difficult in gynecological procedure where hysteroscopy is combined. Pulmonary edema is prevented by monitoring fluid input and output. Intraoperative diuretics should be administered if a large discrepancy between fluid input and output is found. If a patient develops respiratory distress, pulmonary edema should always be considered. Rales couple with classic chest radiographic findings that will confirm the diagnosis.

ADJUNCTS DURING LAPAROSCOPIC SURGERY

Patients with compromised cardiovascular status, obese, old age, and respiratory diseases may have an exaggerated response to pneumoperitoneum. An anesthesiologist aims at controlling and modifying these hemodynamic changes. Various pharmacological agents such as opioids, dexmedetomidine, clonidine, beta-blockers, nitroglycerin (NTG), pregabalin, gabapentin, and magnesium sulfate ($MgSO_4$) have been tried with varying success to provide hemodynamic stability during pneumoperitoneum.

Dexmedetomidine

Dexmedetomidine, an alpha-2 agonist, acts by inhibiting the release of catecholamines and vasopressin. It is known to provide excellent sedation and analgesia with minimal respiratory depression. Dexmedetomidine was found to reduce the requirements of other anesthetic agents and opioids, with minimal side effects, when used at a loading dose of 0.5–1 μg/kg over 10–15 minutes followed by a continuous infusion of 0.2–0.5 μg/kg/h.

Clonidine

Clonidine, an alpha-2 agonist similar to dexmedetomidine, is a potent antihypertensive drug that suppresses renin-angiotensin-aldosterone system (RAAS). Clonidine administered in a dose of 4.5 μg/kg was found to decrease mean arterial pressure (MAP) and heart rate (HR) significantly during and after pneumoperitoneum.

Beta-blockers

Beta-blockers as esmolol, an ultra-short-acting cardio-selective beta-1 receptor antagonist, has been routinely used in a loading dose of 1 mg/kg over 5 minutes followed by 0.5 mg/kg/h in attenuation of stress response to laparoscopy.

Magnesium Sulfate

Administration of $MgSO_4$ was found to attenuate the increase in arterial pressure during CO_2 pneumoperitoneum.

Pregabalin

Pregabalin, an antiepileptic drug, is effective in controlling neuropathic component of acute nociceptive pain of surgery by inhibiting voltage-gated calcium channels. The hemodynamic stability provided by oral premedication might enable laparoscopic surgery in obese, hypertensive, and cardiac compromised patients with no risk of postoperative respiratory depression.

POSTOPERATIVE CONSIDERATIONS

At the end of the procedure, antagonism of the residual muscle relaxation should be reversed by appropriate dose of reversal agents. When patient is awake, he or she should be extubated and transferred to the recovery room in a semirecumbent position. Before extubation, the patient's stomach may be emptied with an orogastric tube. During the next 5 hours in the postoperative period, analgesia should be achieved. Patients spend a minimum of an hour in the recovery room. Vital signs and O_2 saturation are monitored and supplemental O_2 is administered by mask or nasal prongs.

Nausea is frequent after general anesthesia and laparoscopic surgeries. IV droperidol, ondansetron, or dexamethasone can be given for prevention of postoperative nausea and vomiting (PONV).

Multimodal analgesia with nonsteroidal anti-inflammatory drugs (NSAIDs), short-acting opioids, dexmedetomidine, and local infiltration of local anesthetics provide superior pain relief with reduced PONV and early discharge. Following laparoscopic cholecystectomy surgeries, ropivacaine nebulization of intraperitoneal cavity, with or without fentanyl, provides highly effective postoperative analgesia, with decreased incidence of shoulder pain. Furthermore, addition of fentanyl to ropivacaine prolongs the duration of analgesia. Another approach is ultrasound-guided peripheral nerve blocks such as transverse abdominis plane (TAP) block and posterior quadratus lumborum block (QLB).

The urine output should be at rate of 100 mL/h and that should continue for 18 hours postoperatively. The nursing management included O_2 therapy, early mobilization, incentive spirometry, and chest physiotherapy. These should repeat at 2 hours interval. She or he should be transferred to the surgical ward and may be discharged home next day if everything is alright. On the morning of the first postoperative day, the patient should be mobile, pain free, and should start soft diet.

All procedures under anesthesia carry small but inherent risks and patient should understand these before agreeing to undergo the procedure. However, the risks of anesthesia for elective surgery under modern conditions are very small indeed.

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