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Laparoscopic surgery in the high risk patient

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LAPAROSCOPIC SURGERY IN THE HIGH RISK PATIENT

INTRODUCTION

Anaesthesia for laparoscopic surgery in high risk patients (Cardiac and pulmonary disease)

Laparoscopic surgery is a rapidly evolving and expanding field in the domain of minimally invasive surgery. It is fast becoming the standard of care for a variety of procedures, offering many benefits and improved outcomes. Recovery times are shorter with patients quickly returning to normal function: a highly attractive outcome! Anaesthesia for laparoscopic surgery may appear to be a simple procedure for the anaesthetist; it is usually associated with being minimally invasive and low risk, and has therefore inherited the application of the “standard” anaesthetic to the patient. The common recipe that most are familiar with is as follows: general anaesthesia utilising a cuffed oral endotracheal tube (COTT), neuromuscular blockade and positive pressure ventilation. With the evolution of both laparoscopic surgery and anaesthesia, this “standard” procedure has been critically examined and many other anaesthetic options and techniques have come to the fore.

Surgery types are ranging from the very simple to complex procedures, and at times high-risk patients present for surgery where they may previously have been excluded based on their disease severity. This presents a unique challenge for the anaesthetist as there a lot of factors to consider in terms of the risks and benefits of laparoscopic surgery. Depending on the type of surgery performed and the patient’s physical fitness, it is very important to find a technique which can find a balance between the physiological effects of laparoscopic surgery, patient comfort and the optimal operating conditions.

The benefits of laparoscopic surgery:

1. Shortened postoperative recovery period – This is due to a multitude of factors; There is reduced manipulation of the bowel and peritoneum, thus reducing postoperative ileus and facilitating early enteral intake. Early feeding limits the intravenous fluid administration which also promotes faster wound healing with a reduction in tissue oedema. Laparoscopic surgery is associated with a lower systemic stress response than open surgery (1, 2). This may be attributed to lesser tissue injury, reduced inflammation and less immune dysfunction as compared with open surgery. The smaller wound sites also reduce pain. With advancing surgical techniques sometimes requiring fewer port sites faster wound healing is promoted with a reduced risk for systemic infection (1).

2. Benefits in specific patient populations – Short term mortality rates have been reduced with the advent of laparoscopic bariatric surgery versus open surgery (2). Those patients with severe respiratory disease may also benefit from reduced respiratory complications by avoiding abdominal splinting of respiratory efforts secondary to large abdominal wounds from open surgery(3). The proposed reduction in post-operative stress response may also be beneficial in patients with cardiac dysfunction. Patients within a fast track programme may benefit from endoscopic surgery with earlier recovery.

Other benefits include better cosmetic results from the smaller incisions.

The physiological effects of laparoscopic surgery

Before discussing the high risk patient it is essential to know the basic anaesthetic issues involved when preparing for a case for laparoscopic surgery – we need to be keenly aware of the physiological demands and related risks. The major issues are the *pneumoperitoneum* created, the *positional changes* to facilitate the surgery, and surgical equipment used. We also take into account the patient's *pre-operative condition* - all of which have a significant effect on the patient's physiology in response to the pneumoperitoneum and positional changes.

We can divide these into **patient**, **position**, **surgical** and **pneumoperitoneum** related risks

1. Patient factors

The patient's preoperative comorbidities and severity/control of these may preclude them from having a laparoscopic procedure due to the risks possibly outweighing the benefits. The generally accepted contraindications to laparoscopic surgery include intracranial hypertension, right-to-left intra-cardiac shunts, a patent foramen ovale and severe uncorrected hypovolaemia. There are other traditional contraindications to laparoscopic surgery but the overall risks and benefits must be evaluated. These include severe ischaemic heart disease, valvular heart disease, renal disease and end stage respiratory disease(3).

2. Surgical Risks

- Related to trochar insertion – vascular injury – venous haemorrhage may be masked by venous tamponade caused by the pneumoperitoneum. Caution must be taken with delayed presentation of significant haemorrhage from retroperitoneal bleeding which may be insidious in nature.

- Unintended injury to bowel or solid organs with trochar insertion. Patients with abnormal anatomy due to pathology may be at increased risk.

- Gas embolism – this will be discussed later

3. Positional effects

The position changes can be extreme in terms of Trendelenburg and reverse Trendelenburg positions. These are necessary to improve the surgeon's visibility of the operative field. Both however cause significant physiological changes, which is often exacerbated in combination with the purposeful pneumoperitoneum, and significant comorbidities.

Trendelenburg

This is the classic 45 degree head down tilt but now also describes any degree of head down tilt. The severity of the physiological effects of this position is related to the degree of tilt. It is commonly used for gynaecological procedures. The complications can be described in a systems wise approach:

- Movement on the operating table – this obviates the need for securing the patient well using shoulder supports, lower limb straps, careful attention to protecting pressure points.
- Caution should be exercised with shoulder supports may also cause brachial plexus injuries from compression effects.

- GIT – raised intra-gastric pressures and passive regurgitation may cause pulmonary aspiration
- Ophthalmic – raised intraocular pressure
- Neurological – reduced cerebral venous return increasing the risk of cerebral oedema
- Cardiovascular/Vascular – venous return is augmented by gravitational effect with a resultant increase in cardiac output. Despite this, blood pressure is minimally affected due to compensatory vasodilatation.
  Well leg compartment syndrome has been described – where a combination of reduced lower limb arterial perfusion and venous drainage results in a compartment syndrome diagnosed post operatively. Arterial perfusion is impaired by lower limb elevation and the venous drainage is impaired by the pneumoperitoneum and lower limb strapping. The effects may be mitigated by avoiding the use of pneumatic calf compression pumps, using heel-ankle supports, 2 hourly return to horizontal position with massage and early recognition by monitoring pulse oximetry on the toe. Risk factors include – steep Trendelenburg, >4 hours of surgery, peripheral vascular disease, hypotension, obesity and muscular lower limbs(3).

- Respiratory – the cephalad excursion of the diaphragm caused by the head-down-tilt (as well as due intra-abdominal distension from the pneumoperitoneum), reduces pulmonary compliance and functional residual capacity (FRC) and also encourages basal alveolar atelectasis. This exacerbates ventilation-perfusion (V/Q) mismatching causing hypoxaemia.

- Airway complications - movement of the lungs and carina increases the risk of endobronchial intubation and resultant hypoxaemia. Upper airway swelling secondary to dependency effects predisposes the patient to postoperative upper airway obstruction and stridor(4).

Reverse Trendelenburg

This is a head-up-tilt position, commonly used in upper gastrointestinal surgery. The respiratory effects are minimal in this position. Caution must also be exercised in preventing airway device displacement. The cardiovascular effects are more significant here with a reduction in venous return and subsequent reduced cardiac output and hypotension. This will be exaggerated in patient with cardiovascular disease and hypovolaemia.

The other important risk is that of venous-gas-embolism similar to the mechanism in the sitting position. Beneficial effects are opposite to Trendelenburg with improved head and neck, as well as cerebral venous drainage with a reduction in intracranial pressure(5).

4. Pneumoperitoneum

The effects here are predominantly caused by a raised intra-abdominal pressure (IAP) secondary to the purposeful pneumoperitoneum from intra-abdominal gas insufflation. The severity of the physiological changes is directly related to the insufflation pressure reached. Carbon dioxide (CO_2) is usually insufflated at a rate of 1-6 litres per minute to a pressure of 10-20 mmHg(4). These effects also overlap with and are exacerbated by those due to the

Trendelenburg position (noted above). Intra-abdominal hypertension is defined as a raised intra-abdominal pressure >12mmHg. When the pressure is persistently raised >20 mmHg with the development of new organ dysfunction – it has evolved into the more severe entity: Abdominal compartment syndrome (i.e. requiring urgent decompression to avoid serious organ dysfunction, morbidity and mortality).

These can be divided in to Mechanical IAP, gas absorption and gas insufflation effects:

- **Cardiovascular**
  These effects relate to the timing of insufflation and level of intra-abdominal pressure:
  At initial insufflation (IAP<10mmHg), venous return (VR) will be augmented due to splanchnic vessel compression, causing an initial increased cardiac output. Further increases in the IAP (>10mmHg), cause vena caval compression with reduced venous return and reduced cardiac output.

  - *Systemic vascular resistance (SVR)* – an increase in SVR is due to aortic compression by the increased intra-abdominal pressure. Other contributors to an increased SVR are: a neuro-hormonal stimulated release of vasopressin, an increase in circulating catecholamines and stimulation of the renin-angiotensin-aldosterone system (RAAS), in response to aortic compression.

  - *Blood pressure (BP)* - Initially hypertension can occur due to the SVR being raised to a greater degree than the drop in cardiac output. This occurs more commonly at the beginning of insufflation which is due to the splanchnic blood volume auto transfusion as a result of the increased IAP. This causes an increase in preload and arterial pressure.

  - *Cardiac output (CO)* – Changes occur as discussed above. In addition the abdominal distension causes reduced pulmonary compliance resulting in raised intrathoracic pressure, further limiting venous return and cardiac output. These effects cumulatively cause an increase in myocardial work and are exaggerated in patients with myocardial disease and hypovolaemia. This may lead to myocardial ischaemia.

  - *Vagal response* – This can be caused by trochar insertion or peritoneal stretch, resulting in bradyarrhythmias or even cardiac arrest.

- **Respiratory**
  - Abdominal distension causes cephalad movement against the lungs, reducing pulmonary compliance, lung volumes, functional residual capacity, causes atelectasis and ultimately results in V/Q mismatching with hypoxaemia and hypercarbia. (This intra-pulmonary shunting rarely occurs in fit patients)

- **Splanchnic blood flow effects**
  - Raised (IAP) reduces both renal and hepatic blood flow. When the pressure exceeds 20 mmHg, mesenteric and gastrointestinal blood flow is reduced by up to 40 % and can result in tissue hypoxia(3).

- **Renal**

  - Acute kidney injury can arise by renal exposure to persistent raised IAP by a combined mechanism of reduced renal afferent arteriole flow, efferent venous flow as well as obstruction of the urinary outflow tract. This especially occurs at insufflation pressures of > 20 mmHg

- **Neurological**

  - Raised intrathoracic pressures limit cerebral venous drainage increasing the risk of cerebral oedema and intracranial hypertension, with a subsequent reduction in cerebral perfusion pressure (CPP) and postoperative cognitive dysfunction.

- **Gastrointestinal**

  - increased risk of gastric regurgitation
  -Post-operative nausea and vomiting – intra-abdominal gas insufflation and bowel manipulation increases the risk of causing post-operative nausea and vomiting

- **Gas absorption**

  - Hypercarbia also occurs secondary to V/Q mismatching as well absorption of CO_2. The highly soluble CO_2 is readily absorbed through the peritoneum by the circulation, resulting in hypercarbia and acidosis. When CO_2 is administered intraperitoneally, CO_2 excretion is increased by 14–48 mL/min, and returning to a normal CO_2 level can take hours after desufflation after prolonged pneumoperitoneum(6).

  - The effect of CO_2 pneumoperitoneum on the arterial partial pressure of CO_2 ($PaCO_2$) and CO_2 ($ETCO_2$) have been investigated by several studies:

  A study comparing compared laparoscopic Roux-en-Y gastric bypass with open surgery, found that $ETCO_2$ was raised by 14%, whereas $PaCO_2$ also was raised by 10%, from 38 mmHg to 42 mmHg (7). Wittgen et al (8) compared the ventilatory effects of laparoscopic cholecystectomy and found that patients had increased $ETCO_2$ and $PaCO_2$, reduced pH values, in ASA I and II patients, being more pronounced in the ASA III and IV patients.

- Hypercarbia has both direct and indirect sympathetic mediated effects on cardiovascular function. Mild hypercarbia ($PaCO_2$ 45–50 mmHg) has a minimal effect whereas moderate to severe hypercarbia can have a myocardial depressant and direct vasodilatory effect (6). To prevent and address hypercarbia, minute ventilation should be increased by 15%-20%, by increasing the respiratory rate rather than increasing the tidal volume (9).

- **Gas insufflation**

  - *Venous gas embolism* – this is a rare occurrence in laparoscopic surgery (0.0014–0.6%) but with potentially fatal consequences. The severity depends on the rate and volume of gas injection as well as position of the patient (reverse Trendelenburg). Causes can range from injection of CO_2 via the trochar into vessels or organs usually during gas insufflation, or the Venturi effect of gas entering open vessels. The severe effects are less likely to occur in CO_2 embolism, as compared to venous air embolism, due to the higher solubility of CO_2. Preventative measures described are correct insertion of the Veress needle (a spring-loaded needle used to create pneumoperitoneum) with aspiration prior to insufflation, using low insufflation pressures and maintaining central venous pressure above intraperitoneal pressures.

Recognising signs and symptoms of venous gas embolism:

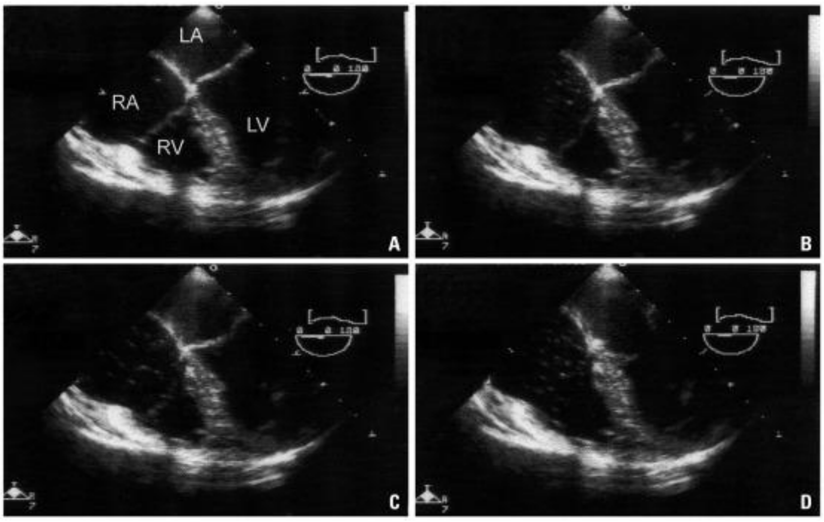
The CO_2 bolus in the local venous circulation travels through the inferior vena cava into the right atrium where a “gas lock” may occur, resulting in severely reduced venous return and hemodynamic collapse (10, 11).

It may present as an initial increase followed by a rapid decrease in end tidal CO_2 ($EtCO_2$), hypotension, and hypoxemia. Cardiac arrhythmias or asystole may occur as well and a “Mill-wheel” cardiac murmur may be auscultated.

Cause	Physiologic change	Sign and symptoms
Gas exchange abnormality	Decreased PaO_2	Dyspnea
	Decreased $PaCO_2$	Cyanosis
	Decreased pH	Hypoxia
Increased RV afterload	Increased PAP	Hypotension
	Cor pulmonale	Chest pain
	RV failure	Murmur
Decreased LV filing	Decrease in CO	Arrhythmia
	LV failure	ECG change of MI
	Cardiac arrest	Sudden death

(12) The Physiological Changes, Signs and Symptoms of Carbon Dioxide Embolism

Transoesophageal echocardiography has been described as the most sensitive method for detecting intravenous injection of carbon dioxide as small as 0.1 mL/kg when compared with $ETCO_2$, pulmonary artery pressure, and precordial auscultation. These detect CO_2 emboli at a similar threshold of 0.5 mL/kg in i (12). Disadvantages of its use include distraction to the anaesthetist of subclinical emboli, technical complexity as well as the operator needing to be constantly monitoring(12).



(12) Gas bubbles in the right atrium (RA) – CO_2 emboli detected by transoesophageal echocardiography in a patient undergoing total laparoscopic hysterectomy; mid-oesophageal four chamber view. (A) A single gas bubble in the RA, right ventricle (RV), and right ventricle outflow tract (RVOT) (grade I). (B) Gas bubbles filling less than half the diameter of RA, RV, and RVOT (grade II). (C) Gas bubbles filling more than half the diameter of RA, RV, and RVOT (grade III). (D) Gas bubbles completely filling the diameter of RA, RV, and RVOT (grade IV).

<u>Management in the event of venous gas embolism:</u>

- The surgeon should be asked to deflate the pneumoperitoneum
- Position the patient in the left lateral position with head down, which allows the gas embolus to accumulate in the right ventricular apex, thus preventing it reaching the pulmonary artery or impeding blood flow through the heart.
- Rapid elimination of CO_2 by increasing the minute ventilation and administer high flows of 100% oxygen.
- Cardiopulmonary resuscitation must be performed in case of asystole, and insertion of a central venous catheter may be considered to aspirate the gas, although this may not be timely
- Hyperbaric oxygen therapy can be used if available.

Management of venous gas embolism (6)

- *Subcutaneous emphysema, pneumothorax, pneumomediastinum, pneumopericardium* – this can occur following peritoneal visceral tear, parietal pleura tear during resection around the oesophagus or congenital defect in the diaphragm through which CO_2 gas travels (6). Pneumothorax and pneumomediastinum can also be caused by an extension of subcutaneous emphysema.

Capnothorax must be differentiated from pneumothorax in that is caused by diffusion of CO_2 into the pleural space.

-*Gasless laparoscopic surgery* – the abdominal lift method has been described as an alternative to a pneumoperitoneum thus avoiding the adverse cardiorespiratory effects.

- *Arrhythmias* – This is due to peritoneal stretch (usually at the beginning of insufflation with rapid peritoneal stretch), causing vagal stimulation with resultant bradyarrhythmias or asystole. Hypercarbia can also results in myocardial dysfunction causing arrhythmias.

The high risk patient

Absolute and relative contra-indications to laparoscopic surgery

As previously mentioned, these patients pose a challenge to the anaesthetist. The physiological effects described above can be exaggerated in high risk patients resulting in peri-operative morbidity or mortality. But why choose laparoscopic techniques? The risks may outweigh the benefits of having a more invasive open procedure. It has been demonstrated that patients who are high risk and undergo traditional cholecystectomy suffer higher morbidity and mortality as compared to laparoscopic cholecystectomy. There are very few absolute contra-indications to laparoscopic surgery, which traditionally included patients with severe ischaemic heart disease, valvular heart disease, significant renal dysfunction, or end-stage respiratory disease due to the fear of perioperative morbidity – especially adverse cardiac events or post-operative pulmonary complications (PPCs). With the evolution of surgery and the attractive benefits of laparoscopic techniques, the decision to operate laparoscopically is now being individualised to include high risk patients. The literature has demonstrated successful cases in patients with severe cardiopulmonary dysfunction, renal disease, cirrhosis, the elderly and the pregnant patients (12). This shift has shown a decrease in the number of previously acceptable contraindications in recent years, and the focus is now on pre-operative risk assessment and procedure indications (12). Relative contra-indications include the following (13), where the risks and benefits should be individualised to the patient similarly.

- Significant cardiorespiratory compromise
- Obesity
- Diaphragmatic hernia
- Significant intra-abdominal adhesions
- Large pelvic mass
- Haemodynamic instability or hypovolaemic shock
- Intestinal obstruction
- Some malignant disease
- Pregnancy

Relative contra-indications to laparoscopic (13)

The patient with Cardiac disease

Laparoscopic cholecystectomy is often discouraged in patients with significant cardiac disease. Severe cardiac disease was previously considered an absolute contraindication to laparoscopy, but the postoperative benefits of minimally invasive surgery may exceed the stress of intraoperative pathophysiological changes(14). Specific concerns include:

1. Pneumoperitoneum - The neuro-hormonal stress response which increases SVR, MAP and heart rate. These factors increase the afterload and myocardial oxygen consumption which are poorly tolerated by patients with cardiac dysfunction. Elevated IAP (usually > 15 mmHg) reduces venous return and preload, and decreases cardiac output. This combination increases cardiac work load and could precipitate cardiac ischemia or infarction. Desufflation can also cause rapid increase in preload, predisposing the patient to cardiac failure and pulmonary oedema.

2. CO2 absorption - The hypercarbia from CO2 absorption causes arteriolar dilatation, arrhythmias and sympathetic stimulation. IAP < 10mmHg usually does not cause significant metabolic or haemodynamic changes. In ASA III and IV patients PEtCO2 does not reflect changes in PaCO2 during insufflations due to changes in alveolar dead space consequent to reduced cardiac output, increased ventilation perfusion mismatch or both. Therefore direct arterial PaCO2 monitoring is recommended in patients with significant cardiovascular disease.

3. Position change – Reverse Trendelenburg position causes a decrease in cardiac output and hypotension due to decreased venous return, which is related to the degree of tilt used. Steep Trendelenburg does augment preload which may not be tolerated by a weak myocardium and cause cardiac failure.

With such potential for haemodynamic instability in already compromised patients, how can we manage this as anaesthetists? A comprehensive pre-operative evaluation including meticulous history taking, clinical examination and risk stratification is paramount to identify the patients at increased risk for peri-operative major adverse cardiac events (MACE). A review of the literature show small case series and studies where successful laparoscopic surgery was performed successfully in patients with a range of significant cardiovascular disease, classified as ASA grades 2-4 (15-17).

1. Sadhu et al 2010 - A prospective study evaluating the safety of laparoscopic cholecystectomy in 28 patients with ischaemic heart disease and significant cardiac dysfunction showed that LC can be safely performed in patients. All patients classified as either NYHA grade 2 or 3, with left ventricular ejection fractions ranging from 20-54%. Patients presented with a range of cardiovascular disease (regional wall motion abnormalities, valvular heart disease, cardiomyopathy and patients with previous cardiac interventions). Commonest events experienced were hypertension (during initial insufflation), tachyarrhythmia and bradycardia – requiring vasoactive drug therapy. All patients had a balanced general anaesthesia technique and low pressure pneumoperitoneum was maintained (17).

Intra-operative course and complications	Number (%)	Treatment
Intra-operative complications	5 (17.9)	
• Persistent HTN	3	GTN
• Hypotension and	1	Desufflation and iv
• bradycardia		pressor support
Tachyarrhythmia	1	Amiodarone
Post-operative complication	4 (14.3)	
• Tachyarrhythmia	3	1: defibrillator
• Acute myocardial infarction	1	
30 day mortality	1	

Results of laparoscopic cholecystectomy in 28 patients with cardiac co-morbidities(17)

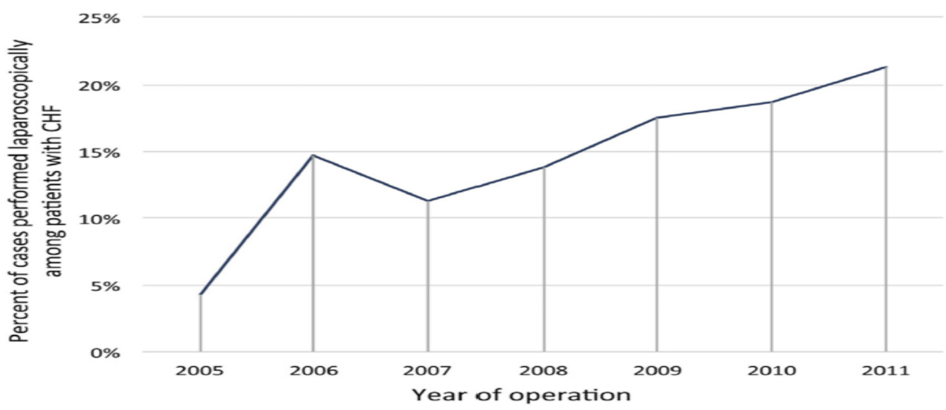
2. Koivusalo 2008 A randomised control trial comparing the CO2 pneumoperitoneum to abdominal lift laparoscopic surgery in high risk ASA 3 and 4 patients - no significant difference in CVP, pH and haemodynamic parameters (oxygenation, perfusion, and blood chemistry) (16).

3. Carroll BJ et al performed laparoscopic biliary operation in 13 patients who had severe cardiac dysfunction with EF <30%. They inferred that laparoscopic surgeries can safely be performed in severe cardiac dysfunction patients with adequate perioperative support and appropriate hemodynamic monitoring (18)

4. Zollinger A et al studied various hemodynamic effects of pneumoperitoneum in cardiac patients and compared with normal individuals. In their study they concluded that pneumoperitoneum produces significant but relatively benign hemodynamic changes. They also concluded that with adequate hemodynamic monitoring laparoscopic surgeries can safely be performed in ASA class III patients with increased cardiac risk(15). Most of the studies used additional haemodynamic monitors such as invasive arterial blood pressure and cardiac output monitors.

5. Safran 1993 – A case series of 15 patients with severe cardiac disease (ASA grades 3 or 4) undergoing laparoscopic cholecystectomy, showed that while laparoscopy presents serious hemodynamic stress, it can be performed safely in high-risk patients, using aggressive intraoperative monitoring.

6. Speicher 2014 – A review of laparoscopic general surgical procedures from 2005-2011 showed that laparoscopic surgery was used less frequently in patients with congestive heart failure (CHF) compared to patients without CHF, particularly for non-elective procedures. They inferred that it was therefore safe to perform laparoscopic surgery in patients with CHF. (Data was retrieved from National Surgical Quality Improvement Program Participant User File). There was however an apparent increasing trend for of laparoscopic surgery being performed in CHF patients. The study also suggests that, for patients with recently diagnosed or worsening CHF who require major general surgery procedures, laparoscopy is as safe as the traditional open approach(19).



Anaesthetic management

Pre-operative evaluation:

This includes a meticulous history and clinical examination which alerts us to the patient's disease severity and therapeutic control. Importantly risk stratification and functional status assessment identifies those patients at high risk for major adverse cardiac events (MACE). A useful and validated guide for risk stratification and investigations would be the 2014 ACC/AHA Guideline on Perioperative Cardiovascular Evaluation and Management of Patients Undergoing Non-cardiac Surgery.

Investigations

1. Laboratory investigations – these can be performed depending on co-morbidities and nature of procedure. Account for anticoagulation therapy.
2. Resting electrocardiograph (ECG) – a baseline can be used to compare to peri-operative ECG traces.
3. Transthoracic echocardiography – Although Left ventricular ejection fraction (EF) can indicate severity of systolic dysfunction, it is not included in risk stratification scoring systems, and so cannot preclude patients from laparoscopic surgery. A cut off of 40% is suggested but patients with lower EF'S have successfully had surgery(20).

Optimisation: ideally the patient's condition should be optimised therapeutically prior to elective surgery and the ACC/AHA guidelines should be used here.

Informed Consent regarding the high risks of MACE, invasive monitoring, anaesthetic technique, and postoperative care and analgesia management is imperative

General Anaesthesia

Goals: Avoidance of drug induced myocardial depression, maintenance of myocardial contractility, maintenance of sinus rhythm, prevention of hypotension to prevent myocardial hypoperfusion and maintenance of adequate preload while preventing fluid overload (21).

The understanding of the nature of the cardiac disease is imperative for management. For example patients with heart failure (HF) are more prone to develop cardiac complications than patients with ischaemic heart disease during laparoscopy, and those with aortic outflow obstruction and left ventricular hypertrophy are extremely sensitive to changes in afterload, particularly during insufflation.

Balanced anaesthesia technique with a cuffed endotracheal tube and mechanical ventilation is recommended here.

Haemodynamic management:
We should anticipate changes in haemodynamic parameters with prompt treatment. Securing an invasive arterial blood pressure monitor awake would aid in this. In addition continuous ST segment analysis can be used to detect myocardial ischaemia. Vasoactive and antiarrhythmic drugs should be available in advance and a defibrillator should be nearby. In all of the studies different cardiac output monitors were utilised, which can guide fluid therapy where judicious fluid therapy should be used to avoid cardiac failure. Elliott et al in a study using trans-oesophageal echocardiography (TOE) during LC in patients with cardiac disease and healthy patients found that significant cardiovascular changes occur during insufflation of CO_2 and they recommended the use of TEE in patients with limited cardiac function. The equipment and expertise are not always available.

Drugs for induction and maintenance:
This can be tailored to the patient and procedure type. Agents can used to blunt the intubation response and for haemodynamic management at moments of instability. Laparoscopic surgery is associated with post-operative nausea and vomiting, and prophylaxis would be advisable. Nitrous oxide is traditionally avoided as it may cause bowel distension and post-operative nausea and vomiting.

Pneumoperitoneum and tilt management
Low insufflation pressures and a mild degree of should be used to limit haemodynamic effects. An IAP threshold of 12 mmHg is associated with minimal changes in the hemodynamics (16). .This is of course provided that the surgeon is comfortable with and has agreed to these conditions pre-operative.

Regional anaesthesia:

This can be used as an adjunct to GA for intra- and post-operative analgesia, such as rectus sheath blocks, TAP blocks, inguinal blocks and caudal blocks. Epidural anaesthesia with GA would supplement intraoperative analgesia, thereby decreasing the requirement of myocardial depressant inhalational anaesthetic agents.

Careful selection of patients and procedures leads to safe use of regional anaesthesia as a sole anaesthetic technique. Caution should be exercised with sedation as this may cause respiratory compromise

Gasless laparoscopy:

To avoid the complications of pneumoperitoneum, gasless laparoscopic cholecystectomy (abdominal wall lifting) has been used as an alternative to laparoscopy in high risk patients. Although abdominal wall lifting is associated with less circulatory changes and improved postoperative cognitive function, there is increased risk of surgical error. The combination of abdominal lift and minimal IAP (4mmHg), may improve surgical conditions.

What to consider when anaesthetising a patient with cardiac disease
- Using Low insufflation pressures
- Gradual and Minimal tilt
- Advanced haemodynamic and carbon dioxide monitoring
- Anticipation, prompt identification and management of haemodynamic instability (hypertension, hypotension) – drugs should be prepared preoperatively.
- Slow smooth insufflation and release of the pneumoperitoneum

The patient with pulmonary disease

Pulmonary disease, depending on the severity, can be quite challenging for the anaesthetist owing to the risk of peri-operative and post-operative pulmonary complications (PPCs), and other associated morbidity. The global prevalence of chronic obstructive pulmonary disease is expanding (9-10% in adults older than 40 years) due to the increase in smoking behaviour and longer life expectancy(22). More high risk patients are then presenting for laparoscopic surgery, which in itself can worsen respiratory function due to the effects of pneumoperitoneum and CO2 absorption (hypercapnia and acidosis). Patients with COPD already have problems of expiratory airflow limitation, possible parenchymal destruction with resultant alveolar hypoventilation, altered respiratory mechanics and ventilation-perfusion (V/Q) mismatching. These changes can ultimately lead to respiratory failure. On the other hand patients with respiratory disease may reap significant benefit from laparoscopic surgery such as shorter recovery times, smaller wounds, avoiding chest splinting and worsening of pulmonary function.

General anaesthesia is also associated with adverse effects on the respiratory system (see table below), and may be more pronounced in patients with respiratory disease, placing them at high risk for general anaesthesia. Although GA is the traditionally accepted method of anaesthetising patients for laparoscopic surgery, the literature has shown that regional anaesthesia can be used safely in healthy patients, with specific precautions taken by the anaesthetist and the surgeon.

1	**Lung parenchyma**
	Decreased lung volume and vital capacity
	Increased closing volume
	Decreased lung compliance
	Increased ventilatory work
2	**Airways**
	Bronchodilation (inhaled anesthetics)
	Bronchoconstriction
	Decreased mucociliary clearance
3	**Ventilatory control**
	Reduced ventilatory response to hypercapnia, hypoxia, and acidosis
4	**Pulmonary circulation**
	Reduced reflex vasoconstriction to hypoxia (inhalation anesthetics)
5	**Gas exchange**
	Increased alveolar–arterial O_2 gradient secondary to change in V_A/Q ratio
6	**Immune function**
	Decreased bactericidal activity of alveolar and bronchial macrophages
	Increased release of proinflammatory cytokines

Effects of GA on the respiratory system (23)

A review of the literature has described successful laparoscopic surgery under regional anaesthesia alone in patients with advanced chronic obstructive pulmonary disease (specifically COPD). Pursnani et al (24) showed the successful use of epidural anaesthesia for laparoscopic cholecystectomy in ASA grade III/IV patients with COPD. Shoulder tip pain was managed with alfentanil and adequate analgesia was provided post-operatively by continuous epidural analgesia. Low pressure pneumoperitoneum was used (10mmHg), and it was noted that no adverse cardiorespiratory events occurred intra- or post-operatively. Gramatica et al concluded that epidural anaesthesia was a safe and feasible technique in patients with cardiorespiratory problems undergoing laparoscopic cholecystectomy. They included ASA grade 3 and 4 patients with COPD, some of which had severe disease and associated pulmonary hypertension. They reported adequate pain control post-operatively, with no conversion to general anaesthesia, no adverse cardiorespiratory problems, and shoulder pain was treated effectively.

When performing general anaesthesia for laparoscopic surgery, we must take precautions throughout the anaesthetic to limit respiratory compromise: Avoiding triggering bronchoconstriction by careful airway instrumentation and avoiding airway irritants such as Desflurane at induction. During mechanical ventilation monitoring for and avoiding excessive airway pressures are important. Desufflation of the pneumoperitoneum and reduction in the degree of tilt can assist in reducing excessive airway pressures. Expiratory airflow limitation must be accounted for by increasing the I:E ratio (1:3-1:5), and we must be aware of air trapping and intrinsic PEEP (PEEPi). Air trapping exposes the lung to barotrauma, volutrauma, hypercapnia and acidosis– this can be limited by the careful application of PEEP as well as prompt treatment of bronchoconstriction. An experienced surgeon should be involved as surgery in excess of 2.5–4 hour duration has been identified as a strong predictor of PPCs (22). Neuromuscular blockade must be adequately reversed to avoid hypoventilation, poor cough and secretion clearance, and pulmonary aspiration. Similarly cautious use of opioids will avoid respiratory depression and resultant hypoxia and hypercapnia. It has been described that extubating the patient straight to non-invasive ventilation may reduce work of breathing and air trapping, thereby reducing the need for reintubation post-operatively. (22)

Postoperative pulmonary function is highly dependent on post-operative analgesia. A multimodal approach, especially the combination of regional and general anaesthesia can provide effective postoperative pain control. Epidural analgesia may be particularly suitable as it is an opioid-sparing technique, reducing the risk of respiratory depression.

The risk and severity of postoperative complications are generally proportional to the degree of clinical impairment and preoperative spirometry. Prognosis is worse in patients presenting with pulmonary hypertension and need for home oxygen therapy.

Preoperative evaluation + risk assessment:

A comprehensive preoperative evaluation should ideally commence well in advance for investigation and optimisation of respiratory function. This assessment is paramount in considering the patients risk for post-operative pulmonary complications, which are of course increased in patients with pre-existing lung disease. There are many risk factors for the development of PPCs which are patient, surgical and anaesthetic related. Patients presenting with advanced respiratory disease may not be eligible for general anaesthesia and combined with the pneumoperitoneum, may not be eligible for general anaesthesia. From the history and examination you should be able to assess the control and severity of the disease. Pulmonary hypertension and right ventricular involvement are important sequelae to elicit. Commonly co-existing comorbidities such as ischaemic heart disease must also be evaluated. No diagnostic tests alone should be used to for assess risk; rather the combined picture of the patient's symptoms, examination, functional status and spirometry should be used.

Investigations:

Electrocardiograph – look for evidence of right ventricle involvement, pulmonary hypertension and ischaemic heart disease

Pulmonary function testing - Spirometry is useful to confirm the diagnosis and to assess the severity of COPD. However the result should not be used alone, as they do not appear to directly correlate with PPCs (25).

Arterial blood gas – predictors of patients at high risk (PaO_2 < 5.9 kPa, $PaCO_2$> 7.9 kPa)

Post-bronchodilator FEV_1/FVC	FEV_1 % predicted	NICE clinical guideline 12 (2004)	ATS/ERS[a] 2004	GOLD 2008[b]	NICE clinical guideline 101 (2010)
		Severity of airflow obstruction			
			Post-bronchodilator	Post-bronchodilator	Post-bronchodilator
<0.7	≥80		Mild	Stage 1 - Mild	Stage 1 - Mild*
<0.7	50-79	Mild	Moderate	Stage 2 - Moderate	Stage 2 - Moderate
<0.7	30-49	Moderate	Severe	Stage 3 - Severe	Stage 3 - Severe
<0.7	<30	Severe	Very severe	Stage 4 - Very severe**	Stage 4 - Very severe**

Classification of severity of airflow limitation in COPD(27)

Optimisation:

Smoking cessation (>8weeks) – Maximal benefit from cessation is obtained if smoking is stopped at least 8 weeks before surgery (some studies suggesting that cessation <8 weeks before surgery is associated with increased risk of PPCs). Optimal medical and nonmedical therapy must be instituted for wheezing, which includes bronchodilators, steroids, incentive spirometry and physiotherapy. Chest infections must also be aggressively treated and elective surgery postponed.

Specific concern relates to CO2 absorption during the pneumoperitoneum in patients with COPD, where hypercapnia may already be present can be controlled with mechanical ventilation. If GA is contra-indicated, those with advanced disease who received regional anaesthesia as a sole technique in the studies did not appear to suffer respiratory compromise from the pneumoperitoneum. A case study of a patient with severe COPD and pulmonary hypertension, requiring home oxygen therapy, reported a safe laparoscopic cholecystectomy after continuous spinal anaesthesia with no respiratory compromise (22).

What to consider in patients with pulmonary disease for laparoscopic surgery

- Pre-operative evaluation (disease severity, functional status) and risk assessment for PPCs
- Risks for general anaesthesia
- Option of regional anaesthesia
- Low insufflation pressures
- Using minimal Trendelenburg tilt
- Use of insufflation gas other than carbon dioxide to avoid CO2 absorption (N2o, Helium, Argon)
- Gasless laparoscopic surgery – this may be associated with more surgical difficulty but avoids complications of pneumoperitoneum

Anaesthesia technique: general versus regional anaesthesia

The challenges the anaesthetist needs to consider include those relating to the pneumoperitoneum, positional requirements, monitoring and all whilst there is restricted access to the patient in a poorly lit environment. In addition to this, high risk patients may suffer exaggerated physiological changes undergoing laparoscopic procedures. These patients require adequate peri-operative planning, monitoring and appropriate post-operative care. The types of surgery being performed are also becoming more complex/major, and cannot be assumed to be simple or of short duration. A well experienced and vigilant anaesthetist is imperative when managing the high risk patient for laparoscopic surgery.

As mentioned the traditional anaesthetic approach was a general anaesthetic with an endotracheal tube, neuromuscular blockade and controlled ventilation. This achieved control over ventilation and etCO2 targets, a comfortable and unaware patient whilst being positioned in the extremes and a protected airway. More recently different techniques have been explored, especially in regional anaesthesia. Concerns regarding a neuraxial-only technique are the higher level of block required, hypotension and the difficulty that can be encountered in controlling shoulder tip pain, but it does have certain benefits in that may be desirable in high risk patients.

No anaesthetic technique has been proven to be clinically superior; but general, local and regional anaesthesia have all been used, often in combination, successfully. Regarding the anaesthetic technique used, there has been a focus on laparoscopic gynaecological procedures and cholecystectomies, with the fairly recent appearance of other surgeries being performed laparoscopically (bariatric surgery, urological procedures, adrenalectomies, appendicectomies, adrenalectomies, colorectal surgery etc.).

- **General anaesthesia**

General anaesthesia (GA) was the traditionally used technique for laparoscopic surgery. The availability of anaesthetic agents which are rapidly-acting and have a shorter-duration of action allow for a faster recovery from GA (Propofol, Remifentanil, sevoflurane, desflurane). This has made GA favourable technique for day-care laparoscopic procedures(26). It also ensures a protected airway if an endotracheal tube is used. Studies have demonstrated the successful use of the Proseal laryngeal mask airway (LMA) with controlled ventilation in selected non-obese patients undergoing laparoscopic procedures. It has been advised that this should rather be used in conjunction with low intra-abdominal pressures and mild tilt (26). The problem of CO2 absorption and hypercapnia is easily addressed by using controlled mechanical ventilation to counter the adverse effects of the pneumoperitoneum. The risk of the patient suffering intraoperative anxiety, abdominal discomfort or shoulder tip pain is also avoided.

Early studies looking at laparoscopic surgery for patients that posed high risk for general anaesthesia were the first to use regional-only techniques (27). This is especially relevant in patients with significant pulmonary disease where controlled ventilation and pneumoperitoneum effects may cause significant PPCs. There are also the risks associated with airway manipulation (invasive, oral/dental damage, post-operative sore throat, intubation response in patients with cardiovascular compromise). The endotracheal tube may be displacement and causing hypoxaemia, especially during positional changes. Higher mean and peak airway pressures associated with the pneumoperitoneum can expose the patient to further risk of cardiovascular compromise and pulmonary injury

- **Regional Anaesthesia**

    - Neuraxial anaesthesia (Spinal , epidural and combined spinal epidural anaesthesia)

The beneficial effects of regional anaesthetic techniques include improved pulmonary function, decreased cardiovascular demands, reduced ileus, and improved pain control .A meta-analysis of regional anaesthetic studies showed a 30% reduction in morbidity compared with general anaesthesia(28). Reports of laparoscopic cholecystectomy under neuraxial anaesthesia alone were few and mainly included patients with severe chronic obstructive airway disease who were unfit to receive general anaesthesia(27). In this era of ERAS and minimally invasive surgery, there has been has been a shift to performing more minimally invasive surgeries using techniques that produce a faster recovery period and return to normal function; this has encouraged anaesthetists to explore other techniques. Various studies have suggested that regional anaesthesia alone (spinal, epidural, combined spinal epidural anaesthesia) is a safe alternative to GA in laparoscopic surgery, especially in healthy patients(26). There have been several reports in the literature for the safe use of spinal anaesthesia for both laparoscopic upper and lower abdominal procedures. It has been noted that evidence developing nations is lacking regarding various advancements, possibly due to poor reporting of advancements and innovations(26). Regional anaesthesia has frequently been used in conjunction with GA, to gain the benefits of regional anaesthesia (better post-operative analgesia and reduced deep vein thrombosis).

Advantages of regional anaesthesia:

- No airway manipulation
- The patient is awake and spontaneously breathing patient intraoperatively
- Minimal nausea and vomiting
- Effective post-operative analgesia
- Early ambulation and recovery
- Reduction of surgical stress response
- Lower incidence of deep vein thrombosis

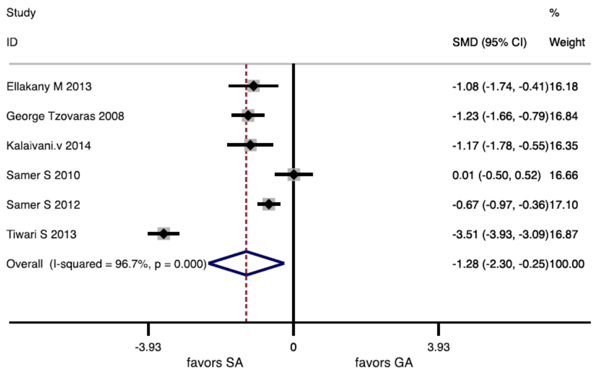
Disadvantages:

- Sudden Hypotension
- Inadequate sensory level
- Shoulder tip pain
- Respiratory compromise due to pneumoperitoneum, carbon dioxide absorption and ventilatory changes with motor level achieved.
- Patient anxiety
- Abdominal discomfort
- Time consuming anaesthetic technique

Review of the literature:

1. A meta-analysis of randomised control trials (RCT) from 2000-2014 compared the use of spinal anaesthesia (SA) as the sole anaesthetic compared to general anaesthesia (GA) for laparoscopic cholecystectomy. This showed SA to be superior to GA in terms of less post-operative pain (within 12 hours) and post-operative nausea and vomiting, but GA caused less post-operative urinary retention(29). There was also no significant difference in operating times between the two groups. Intraoperative shoulder right shoulder tip pain was reported in 26.1% in the SA group which was managed adequately with intravenous fentanyl. Intraoperative hypotension in the SA group was adequately treated with vasopressors when it occurred. Patients may have lower incidence of postoperative complications in the SA group suggesting that laparoscopic cholecystectomy under SA is safe. Limitations to this study

included the significant heterogeneity in the primary outcomes. The authors suggested larger prospective studies be performed.



Forest plots for primary outcomes included postoperative pain scores in 6 to 8 h (29)

2. Donmez(30) – A RCT comparing combined spinal epidural anaesthesia (CSEA) alone versus GA for laparoscopic cholecystectomy showed CSEA to be a suitable and safe technique for LC. They demonstrated less postoperative pain, shoulder pain and post-operative nausea and vomiting in the CSEA group as compared to the GA group, and showed that intraoperative adverse events associated with CSEA can be easily treated. (This included shoulder tip pain, abdominal discomfort and hypotension). All patients in this study were ASA grade <III, and there were no conversions to GA.

3. Bajwa (26) – This review article looked at RCT's comparing neuraxial to general anaesthesia for laparoscopic cholecystectomy. It is interesting to note that all of the studies included used a low pressure pneumoperitoneum (8-10mmHg). The safety of RA among various types of patient populations still needs to be verified. Studies have showed safe use of spinal anaesthesia alone with adequate muscle relaxation for upper and lower abdominal laparoscopic surgery. Concerns mentioned include hypotension which can be worsened by reverse Trendelenburg and pneumoperitoneum. Strategies to mitigate this include preloading, reduced tilt, low pressure pneumoperitoneum and the liberal use of vasopressors.

Epidural anaesthesia can also be a safe technique for lower abdominal surgeries providing adequate post-operative analgesia, with few complications being reported. It has been can be used in patients unfit for GA, providing adequate post-operative analgesia. CSEA has also been used and may be advantageous over epidural/spinal block alone. This includes smaller intrathecal does of local anaesthetic agent, rapid onset of anaesthesia, effective post-operative analgesia and early ambulation. The incidence of side effects can be lowered by reducing the tilt and intra-abdominal pressures. (31)

4. In a case series of laparoscopic appendicectomy performed in ASA grade 1 patients, CSEA appeared to be a suitable option. Patients experienced adequate analgesia up to 6 hours postoperatively and a low incidence of nausea and vomiting (in keeping with previous studies). Notable adverse events were hypotension, abdominal discomfort, shoulder pain and anxiety which were treated effectively (32).

5. Another prospective study(33) evaluated using regional anaesthesia (CSEA) in a variety of laparoscopic surgeries: laparoscopic cholecystectomy (LC) and laparoscopic assisted vaginal hysterectomy (LAVH)/total laparoscopic hysterectomy (TLH), with normal pressure pneumoperitoneum. This showed CSEA to be a safe technique. Adequate abdominal relaxation was reported in the 50 patients included in the study, and an adequate sensory

level was achieved aided by the epidural volume extension effect. Shoulder pain was effectively managed with parenteral fentanyl.

6. Tsovaras et al (34) – A randomised control trial comparing SA to GA (in ASA I and II patients) for laparoscopic cholecystectomy, showed SA to be more effective than the standard general anaesthesia in postoperative pain control during the patient's hospital stay.

7. Imbelloni et al(35) General Anaesthesia versus Spinal Anaesthesia for Laparoscopic Cholecystectomy Laparoscopic cholecystectomy with low-pressure pneumoperitoneum with CO_2 can be safely performed under spinal anaesthesia. Spinal anaesthesia was associated with an extremely low level of postoperative pain, better recovery, and lower cost than general anaesthesia.

From this it is seen that in otherwise healthy patients, regional only anaesthesia may be a safe alternative to general anaesthesia and common complications (such as shoulder tip pain) can be managed effectively.

<u>Management of Shoulder tip pain</u>

This is a common complaint during regional anaesthesia for laparoscopic surgery. The Incidence during laparoscopic cholecystectomy ranges from 4-43%, with the need to convert to general anaesthetic (due to) ranging from 0.06-10% (30). Helpful strategies to deal with this include:

1.Prevention: Counselling of the patient of the risks of discomfort or pain and management options, using low intraperitoneal insufflation pressures (<10mmHg) and minimal Trendelenburg tilting (reducing diaphragmatic irritation), and sub diaphragmatic local anaesthetic aerosolisation(30).

2. Treatment: Reassurance, intravenous short acting opioid, sedation, conversion to general anaesthesia.

General anaesthesia can often be combined with regional anaesthesia, to provide the extended analgesic effect post-operatively. Other regional anaesthesia techniques include: Transversus abdominis plane (TAP) block, rectus sheath block, local anaesthetic wound infiltration, intraperitoneal local anaesthetic (aerosolisation) and paravertebral block. Pedrazzani (30) showed that a TAP block in combination with local wound infiltration in the context of laparoscopic colorectal surgery and ERAS program, results in a reduced use of opioid analgesics and good pain control allowing the improvement of essential items of enhanced recovery pathways.

Outpatient laparoscopic procedures are often performed just using local anaesthesia with good results. Procedures such as inguinal hernia repair and sterilization have been performed successfully. Patients do need adequate counselling pre-operatively, sedation may be used intraoperatively and an experienced surgeon using low insufflation pressures is desirable.

What to consider if using neuraxial anaesthesia as the sole technique

- Adequate communication with the surgery team regarding surgical conditions required in an awake patient
- Adequate counselling of the patient regarding the likely adverse effects and management options (including conversion to general anaesthetic)
- Site of trochar insertion and sensory level of blockade required
- Preloading with intravenous fluid

- Management of shoulder tip pain
- Use of post-operative nausea and vomiting prophylaxis
- Pneumoperitoneum – gradual insufflation (low flow rate 1-2l/min), low pressure pneumoperitoneum (<12mmHg)
- Using mild tilt with positional change

Alternative techniques + future technological advances

Gasless laparoscopy

Mechanical abdominal wall lift (AWL) has been proposed as an alternative to pneumoperitoneum to minimize the adverse effects associated with the pneumoperitoneum. In a randomised controlled trial on patients presenting for laparoscopic cholecystectomy, abdominal wall lift did not alter cardiac function or renal haemodynamics as compared to pneumoperitoneum, and may be useful in patients with cardiovascular or renal disorders(36). The AWL may also be associated with a more rapid recovery of postoperative cognitive function compared with pneumoperitoneum(37). A disadvantage is reduced exposure, causing possible increased surgical difficulty and prolonged surgical time. This may be overcome by combining AWL with low-pressure (3 to 4 mm Hg) pneumoperitoneum.

Robotic assisted laparoscopic surgery

Robotics in surgery are machines that allow surgeons to control their instruments from a distance with a higher degree of precision and control. This would theoretically allow more technically difficult procedures to be performed. A scrubbed assistant is still required to insert instruments through the endoscopic ports and to change the various instruments intraoperatively (38). Robotic surgery also overcomes some of the shortcomings of conservative laparoscopic or endoscopic techniques, such as the assistant-dependent unstable video camera platform, two-dimensional view, restricted ergonomics of the surgeon, and instruments with limited degrees of freedom and the absence of wrist gear(39). These systems now present three-dimensional views with magnification and tools with seven degrees of freedom (DOF) which duplicate hand movements with high accuracy.

Anaesthetists should become familiar with robotic assisted surgery and learn the basic features of robotic surgical systems to tailor their anaesthetic technique, be aware of the relevant issues and ensure patient safety. There are a range of procedures being performed ranging from cardiac, thoracic, abdominal, pelvic to trans-oral robotic assisted surgery. The most common being robot assisted laparoscopic radical prostatectomy (RARP)(39).

Important anaesthetic considerations:

- Bulky equipment restricting space
- Robotic arms may restrict access to the chest for cardiopulmonary resuscitation and airway interventions.
- Poor access to the patient once robotics positioned
- No patient movement is a critical necessity
- More extreme positioning than with conventional laparoscopy

CONCLUSION

The inclusion of high risk patients as candidates for laparoscopic surgery has expanded our challenges as anaesthetists, but all with the common goal of improving outcomes for patients. Minimally invasive surgery has many benefits to patients with co-morbidities as compared to open surgery. The spectrum of laparoscopic surgery is vast in a great number of high risk patients, requiring anaesthetists to remain updated and adjust their techniques accordingly. Such patients include those presenting for bariatric procedures, adrenalectomy, nephrectomy, and pregnant patients. The literature has shown that it is possible to successfully perform a range of laparoscopic procedures on patients with advanced cardiac and pulmonary disease. In order to do this we need to take specific precautions relating to patients' pre-operative evaluation, modifications to the laparoscopic technique to reduce the adverse physiological effects, and appropriate post-operative care. Anaesthetic techniques are also expanding, where regional and local anaesthesia are being used as adjuncts to general anaesthesia. And where general anaesthesia may prove to be detrimental to the patient, regional anaesthesia as the sole technique has also been explored. This has also been performed in studies successfully, but also requires specific intra-operative conditions. An experienced and vigilant anaesthetist should be involved in these cases as they are chosen on a "case-by-case" basis, where the benefit is deemed higher than the risks, but the anaesthetists needs to be wary of these risks and comfortable in managing complications.

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