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Anaesthesia

Anaesthetic considerations for paediatric laparoscopy

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Summary

Children, infants and neonates represent an anaesthetic challenge because of age-specific anatomical and physiological issues. Apart from paediatric-specific anaesthetic considerations, the paediatric anaesthetist must understand the implications of laparoscopic surgery, and prevent and react appropriately to changes that will occur during these procedures. Pre-operative assessment is a multi-specialist responsibility. Predicting the effects on each organ system, planning the strategy required and maintaining open communication within the team ensure the success of the operation and limit peri-operative morbidity.

This review considers the various effects that must be taken into account during laparoscopic surgery in children and neonates in order to: (*i*) enhance the insight of surgeons with respect to these effects; (*ii*) assist in preparing patients for laparoscopic surgery; and (*iii*) allow surgeons to guide anaesthetists who may be unfamiliar with the issues specific to laparoscopic surgery.

History

The successful application of laparoscopic techniques in adults has led to their use in increasingly younger patients.[1,2] Hurdles included cost, lack of surgical and anaesthetic expertise, duration of surgery, and the effects of pneumoperitoneum and pneumothorax on children and neonates.[3]

Over the past 10 years, the number of procedures that have and are being performed in children and neonates has increased. The most common procedures are set out in Table I.[4-8]

The impact of CO_2 pneumoperitoneum on paediatric and the exaggerated effects on neonatal physiology are particularly important in the planning and conduct of anaesthesia to prevent a turbulent peri-operative course.

Physical principles to consider
Gases used for pneumoperitoneum

The characteristics considered optimal for an insufflating gas are listed in Table II. CO_2 is the gas of choice as it does not support combustion, is soluble, thereby reducing the possibility of gas embolus, is readily available and is relatively well tolerated.

Fick's Law of Diffusion

Fick's Law of Diffusion states: Vgas α A/t .D (P$_1$–P$_2$).

In other words, the diffusion of a gas across a membrane is proportional to the area of the membrane in contact with the gas (A), the difference in partial pressure of the gas across the membrane (P$_1$–P$_2$), and a diffusion constant (D) where D $\alpha^{sol}/\sqrt{MW}$. The diffusion is therefore proportional to the solubility of the gas and inversely proportional to the square root of the molecular weight as well as the thickness of the membrane. Hence children will absorb a higher proportion of CO_2 as surface area:body mass is increased and peritoneal thickness is decreased.

Transpulmonary pressure

This concept is vital to the anaesthesiologist's understanding of safe tolerance to increased ventilator pressures during pneumoperitoneum. Transpulmonary pressure is the difference between the alveolar and intrapleural pressure or $P_{tp}=P_{alv}-P_{pl}$.

It is the transpulmonary pressure that is injurious to lung parenchyma. With increasing repetitive transpulmonary pressure there is a greater risk of acute lung injury and acute

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TABLE I. POTENTIAL APPLICATIONS OF MINIMALLY INVASIVE LAPAROSCOPY IN CHILDREN (ADAPTED FROM TOBIAS[22])

Nissen fundoplication
Cholecystectomy
Splenectomy
Ileo-anal pull-through
Inguinal herniorrhaphy
Adrenalectomy
Nephrectomy
Appendicectomy
Diagnostic laparoscopy
Oophorectomy/gonadectomy

TABLE II. IDEAL GAS FOR INSUFFLATION DURING LAPAROSCOPY (ADAPTED FROM TOBIAS[22])

Incapable of supporting combustion
Limited systemic absorption
Limited systemic effects when absorbed
Rapid excretion if absorbed
High solubility in blood
Limited physiological effects with intravascular systemic embolism

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respiratory distress syndrome (ARDS). As illustrated in Fig. 1 (c), pneumoperitoneum increases the external pressure and thereby intrapleural pressure. Transpulmonary pressure is decreased, allowing for a safe increase in ventilator pressures proportional to the pressure provided.

Physiology and pneumoperitoneum

Pneumoperitoneum exerts its effects on organ systems primarily via the physical pressure on those systems and secondly due to the systemic absorption of carbon dioxide. The pressure effect is dependent both on absolute intraperitoneal pressure and the length of time that the pressure is applied. The diffusion of CO_2 across the peritoneum and into the bloodstream is governed by Fick's Law. The physiological effects are increased with decreasing age and weight due to decreased muscle bulk, an increased peritoneal surface area to mass ratio, decreased peritoneal thickness, and decreased organ-specific reserve.

Respiratory effects

The increased intra-abdominal pressure (IAP) results in splinting and a cephalad shift of the diaphragm. This leads to: (*i*) an absolute decrease in functional residual capacity and an increased possibility for atelectasis; (*ii*) decreased lung compliance; (*iii*) increased possibility of bronchial mainstem intubation; and (*iv*) increased V/Q mismatch in different parts of the lung with preferential ventilation of non-dependent regions.

The Trendelenburg position used in pelvic laparoscopy aggravates the negative effects of the increased IAP on respiratory function, with the head-up position reducing respiratory compromise.[8]

In a study of tolerance of laparoscopy and thoracoscopy in neonates[3] the following data are pertinent: (*i*) 58% of patients had a moderate decrease in oxygen saturation (approximately 5%); (*ii*) 88% sustained an average increase of 9.1±5.3 mmHg end-tidal CO_2 (ETCO$_2$) with some cases exceeding 15 - 20 mmHg increases – in 56% of cases hyperventilation did not completely correct the ETCO$_2$, but all cases returned to normal within 15 minutes of cessation of insufflation; (*iii*) pressure (Fig. 2) and duration of CO_2 insufflation (Fig. 3) influenced the variations in ETCO$_2$ – smallest variations were evident with insufflation <6 mmHg; ETCO$_2$ significantly correlated to insufflation pressure and tended to be greater ($p > 0.05$) with longer procedures; and (*iv*) ventilatory pressure change required (peak inspiratory pressure) to limit perturbations in ETCO$_2$ was from 17.3±4 cm H_2O to 22.2±5.4 cm H_2O.
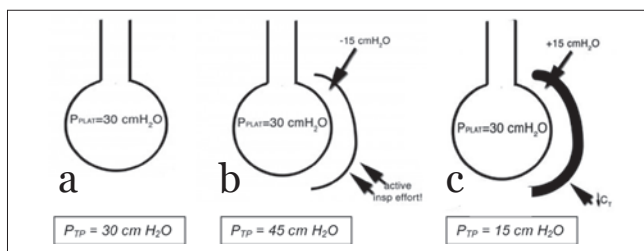

Fig. 1. a: No opposing intrapleural pressure; b: ventilatory pressure = 30 cm H_2O with negative pressure from active inspiration of 15 cm H_2O – P_{tp}= 45 cm H_2O; c: intraplural pressure of 15 cm H_2O (e.g. laparoscopy) – P_{tp}= 15 cm H_2O (adapted from Hess[23]).

Cardiovascular effects

The cardiovascular effects are principally due to a decrease in preload and an increase in afterload. These are the result of increased intra-abdominal pressure during insufflation impeding venous return as well as increasing transaortic pressure in the abdominal cavity which would under normal circumstances be close to zero in an anaesthetised patient.

Systemic vascular resistance increases in response to these changes. This results in maintenance of blood pressure
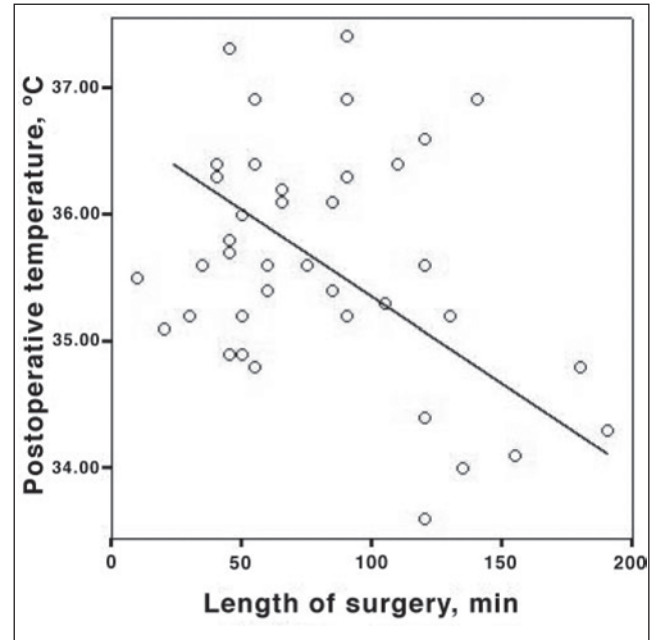

Fig. 2. The mean variation in ETCO$_2$ depends on the insufflation pressure of pneumoperitoneum or pneumothorax (p=0.05) (from Kalfa et al.[24]).
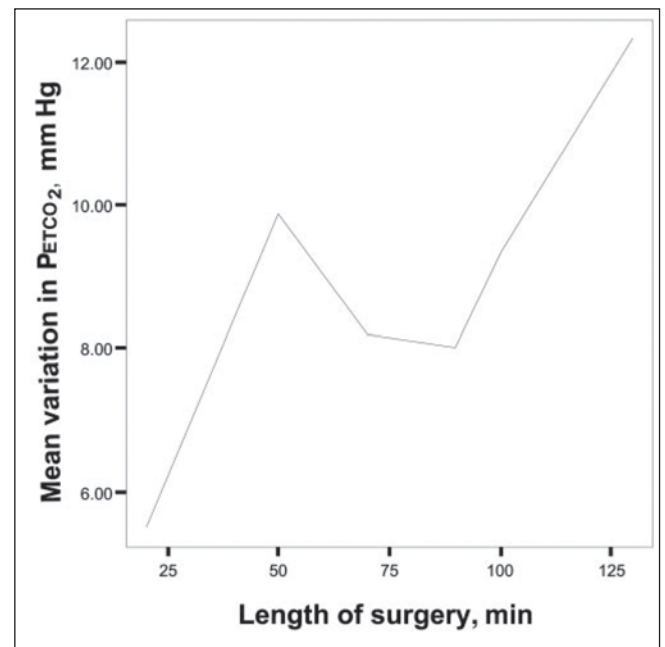

Fig. 3. Variations in ETCO$_2$ according to the length of surgery. The observations were gathered per 25-minute insufflation period. Patients with extreme peri-operative variations in ETCO$_2$ are not represented in this diagram (from Kalfa et al.[24]).

despite an approximate decrease in cardiac output of 30%.[9] Interestingly, insufflation with an IAP <10 mmHg augments preload through the displacement of blood from the splanchnic vasculature, while pressures of >15 mmHg impede venous return.[8]

Patient position greatly influences the cardiovascular responses to laparoscopy with decreases in venous return induced by the reverse Trendelenburg position and an increase with the Trendelenburg position. An estimated 25 - 30% of the blood volume is contained below the waist. In patients with normal cardiovascular function these alterations are usually well tolerated. Those with compromised cardiac contractility may not be appropriate candidates for laparoscopy without appropriate pre-operative evaluation and alteration of intra-operative anaesthetic and surgical technique.[10]

It is important to be aware of the relatively fixed cardiac contractility in infants under 3 months of age and neonates in particular. These babies cannot increase contractility because of immature myocardial fibres and can only increase cardiac output through an increase in heart rate. Due consideration and limitation of extremes of patient position and intra-abdominal pressure are therefore vitally important.

In a review of the cardiovascular effects of laparoscopy on neonates,[3] 80% of patients had a stable blood pressure with a compensatory increase in heart rate (average increase of 20 bpm from 120 - 140 bpm) which resolved on cessation of pneumoperitoneum. Twenty per cent of patients experienced a drop in blood pressure of 10 mmHg or more with a proportion requiring volume expansion for systolic blood pressure <45 mmHg. Thoracoscopy caused the most pronounced drops, probably due to the enhanced effects on preload and afterload.[3]

Central nervous system

The effects of pneumoperitoneum on intracranial pressure (ICP) and cerebral perfusion pressure (CPP) in an animal model were investigated by Bloomfield *et al.*[11] At an IAP of 25 mmHg, the ICP increased from a mean of 7.6 to 21.4 mmHg and the CPP decreased from 82 to 62 mmHg.[11] This would be consistent with the equation CPP = MAP − ICP or CVP (whichever is larger). An increase in intra-abdominal pressure would directly affect the venous drainage from the head and neck, with the Trendelenburg positioning further aggravating the changes.

Renal system

In 1999, Koivusalo *et al.* investigated the effects of pneumoperitoneum on renal function compared with the abdominal wall lift method, and demonstrated a decrease in urine output during laparoscopy as well as an increase in urinary excretion of N-acetyl-beta-glucosaminidase – a marker of renal injury.[12]

Thermic consequences

In the study of neonates by Kalfa *et al.*,[3] postoperative core body temperature was <36°C in 50% of patients and <34.5°C in 12%. The length of insufflation correlated with the temperature increase, with an operative temperature loss in degrees celsius that was 0.01 of the surgical time in minutes. In this study loss was not influenced by patient weight.[3] Newer insufflation devices provide warmed CO_2, avoiding the potential for hypothermia.

Risk factors

Apart from the general risks of insufflation that are not unique to children, infants under 3 months of age suffer more surgical and anaesthetic complications. Insufflation longer than 100 minutes (particularly with thoracoscopy), high insufflation pressures and $ETCO_2$ variations, low body temperature, a need for vascular expansion and major modification of ventilator parameters at the start of insufflation are independent neonatal risk factors.[3]

Practical anaesthesia

While laparoscopy always requires understanding of the physiological and physical impact of insufflation, paediatric laparoscopy and anaesthesia require further considerations. The remainder of this review aims to provide both surgeons and anaesthetists with means of avoiding complications and insights to identify potential problems.

Pre-anaesthetic assessment

The pre-anaesthetic goal is to identify ongoing acute or chronic problems that may affect the plan for anaesthesia.[8] These would include previously undiagnosed conditions (congenital abnormalities and difficult airways), and disease-specific complications that precipitated the need for surgery (e.g. concurrent pneumonia due to reflux, atelectasis, renal failure, systemic sepsis).

Pre-operative laboratory evaluation depends more on the patient's status than on the procedure itself. In neonates, a lower pre-operative body temperature and fractional inspired oxygen of 100% at the start of insufflation predict increased anaesthetic incidents.[3]

The procedure-specific potential for blood loss may necessitate measuring a starting haematocrit as well as cross-matching blood, particularly with declining weight, where relatively smaller volumes result in a proportionately higher risk of shock.

Excluding patients' eligibility for laparoscopy

While there are undoubtedly surgical, recovery and aesthetic advantages to laparoscopic surgery, there are also potential disadvantages, challenges and complications that may place certain patients at an unacceptably high risk. The effects of increased intra-abdominal pressure on several organ systems must be considered during surgical planning and the pre-anaesthetic assessment. End-organ dysfunction and the potential effects of pneumoperitoneum may mean that laparoscopy is a poor physiological choice for certain patients.[8] Examples include hypothermia, inotropic support, unexplained resistant arrhythmias, compromised cardiac contractility, severe respiratory compromise, raised ICP and compromised gastro-intestinal perfusion.

Premedication

Pre-operative medication may not be required in older children, neonates, or infants less than 9 months of age. Midazolam

intravenous preparation mixed with paracetamol-based syrups (to mask the bitter taste) given orally provides effective pre-operative anxiolysis with limited effect on respiratory function.[13] The author's practice is to time the administration of premedication with oral midazolam 20 - 40 minutes before the induction of anaesthesia using sevoflurane in 100% oxygen or 50% nitrous oxide and oxygen for induction only (patient dependent).

Oral anticholinergics such as glycopyrrolate may be combined with midazolam premedication or given intravenously after induction of anaesthesia and placement of the intravenous cannula. Anticholinergic agents act to dry secretions, blunt airway reflexes and prevent reflex bradycardia during abdominal insufflation for laparoscopy.[8]

Anaesthetic induction

In the majority of patients, either intravenous or inhalational induction is acceptable. Patient-specific factors including emergency surgery, predicted airway difficulty, and limited cardiopulmonary reserve may limit the use of intravenous agents that induce negative inotropy and vasodilation.

Intravenous access is more commonly secured in the upper limb because of the theoretical effects of increased IAP and delayed onset time of medications administered more peripherally.

Cuffed endotracheal tubes limit excessive leaks around the tube during insufflation when increased peak inspiratory pressures and the application of positive end-expiratory pressure (PEEP) may be required to counteract insufflation-induced increases in IAP as well as the Trendelenburg position (see also the section on transpulmonary pressure above). A nasogastric tube will decompress the stomach and improve visualisation, and a urinary catheter should be placed for prolonged procedures.

Maintenance of anaesthesia

The majority of anaesthesiologists would opt for a combination of inhalational anaesthesia with intravenous opioids. With specific reference to laparoscopic anaesthesia, avoidance of halothane is suggested owing to its arrhythmogenic properties when hypercarbia is present.

Nitrous oxide is best avoided. It exacerbates postoperative nausea and vomiting and has the possible, albeit controversial, ability to increase bowel distension. There is even some evidence to suggest that diffusion of nitrous oxide into the peritoneal space may occur in sufficient concentrations to support combustion.[14,15]

Most patients will require neuromuscular blockade that should be tailored to the length of the procedure as well as co-morbidities. An anticholinergic agent should be close at hand or may be administered prophylactically to prevent vagal reflexes.[8]

Ventilatory considerations

Children present ventilatory challenges during laparoscopy. This is most evident in neonates and decreases as body mass increases. Small airway calibre and instrumental dead space lead to marked increases in $ETCO_2$. In one series,[3] the 33%

increase in $ETCO_2$ despite ventilator adjustment was far higher than in adults and larger children.[16-18] The peritoneal and pleural absorption surface per unit of weight is high in newborns.[19] The low quantity of peritoneal fat and slight distance between vessels and the serous surface increase the permeability of the peritoneum to CO_2.[3] Increased insufflation pressure (Fick's law of diffusion) and increased duration of insufflation increase CO_2, which in itself will increase the risk of a peri-operative incident.[3]

In consequence, monitoring pre- and post-insufflation peak inspiratory pressures (PIP) and exhaled tidal volumes is important. To control $ETCO_2$ and counterbalance reduced respiratory compliance and increased resistance, a 25 - 30% increase in minute ventilation and increased PIP are likely to be required to maintain normocarbia or limit hypercarbia. The application of PEEP to counteract the effects of increased IAP on the lower lung zones and an increased FiO_2 is often required to maintain acceptable oxygen saturation.

The attention to maximal reduction in dead space with respect to airway instrumentation cannot be over-emphasised in neonates and young infants. Filters designed for use in smaller endotracheal tubes (size 3.0 and 3.5 OD) are commercially available. Where these are not available or CO_2 levels are increasing, removal of the filter may be necessary with $ETCO_2$ monitoring achievable with a 24G needle placed carefully into the ETT at the junction of the connector and the tube.

Increased shunt, dead-space ventilation, absorption across the peritoneum and increased IAP all lead to hypercarbia, as well as causing relative hypoxia with respect to PEEP and FiO_2 requirements. Temporary interruption of pneumoperitoneum and surgery may be required if $ETCO_2$ continues to increase despite ventilator changes, elimination of dead space and optimisation of cardiac output. That stated, several other aetiologies must be considered if cardiorespiratory compromise occurs during laparoscopy (Table III).[8]

Laparoscopic-specific respiratory complications include pneumothorax and CO_2 gas embolism. Especially with upper abdominal procedures (Nissen fundoplication), CO_2 can dissect along the mediastinal fascial planes into the thorax, resulting in pneumothorax.[8] The potential for gas embolism increases with increasing IAP, spontaneous modes of ventilation (leading to negative pressure generation in the venous system), and venous perforation. The physiological consequences of gas

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TABLE III. CAUSES OF VENTILATOR PROBLEMS DURING SURGERY

Endotracheal tube – obstruction/tube migration/ mucous plug
Pneumothorax
Excessive IAP/patient position: splinting → decreased FRC/atelectasis
Decreased cardiac output
Hypercarbia non-responsive – absorption, dead-space acid aspiration, bronchospasm, machine malfunction

IAP = intra-abdominal pressure; FRC = functional residual capacity.

embolism are related to: (*i*) the gas (CO_2, being highly soluble, is safest); (*ii*) its volume; (*iii*) the rate of entrainment; and (*iv*) the patient's haemodynamic and volume status.[8]

When the rate of entrainment exceeds the lung's capacity to excrete CO_2, pulmonary artery pressure rises resulting in right heart failure and dilatation with impedance of left ventricular filling.[8]

Treatment of CO_2 gas embolism starts with identification of the problem. Immediate cessation of insufflation and release of the pneumoperitoneum, increasing the FiO_2 to 1.0, discontinuation of negative inotropic agents (e.g. volatile anaesthesia), and resuscitation with fluid and inotropes to re-establish/improve cardiac output are rational. Exclusion of other causes of hypotension and observed changes in monitoring coupled with ventilator monitors are important (e.g. pneumothorax). Fortunately CO_2 embolism is rare and when it occurs is usually rapidly reversed owing to high gaseous solubility (excluding large emboli), allowing for the continuation and completion of surgery without long-term sequelae.

Cardiovascular, central nervous system and renal considerations

Because of the cardiovascular implications of laparoscopy, it is important to ensure that patients are intravascularly replete at the start of insufflation. This is most important in neonates and young infants, in whom contractility is not variable. In general, however, the haemodynamic tolerance of insufflation in small infants is acceptable. Metabolic tolerance may not be as 'forgiving', so meticulous attention to the patient's fluid requirements throughout the surgery is critical. Insufflation pressures should be kept below 13 mmHg, as the effect of higher pressures is unknown, and arterial pressure readings may not correlate with cardiac output and oxygen delivery.[20,21] IAP should be kept to the lowest possible level that allows adequate visualisation, to limit the effects on all organ systems. Good neuromuscular blockade assists in the limitation of pressures required.

Temperature considerations

Monitoring core temperature is an absolute requirement. Insufflators that do not warm the CO_2 lead to a high incidence of hypothermia, particularly when port leaks occur. Such patients require active convection warming, which may be difficult during long operations. Systems that warm the gas are clearly preferable.

Postoperative care

After completion of the procedure, evacuation of the CO_2 is advised to limit nausea, vomiting and pain. Reversal of all neuromuscular blockade before extubation is ideal. Postoperative analgesia includes local anaesthetic infiltration of the port sites, a regional block (caudal/epidural), intravenous analgesics when patients are admitted to a high-care unit, and tilidine with oral paracetamol and non-steroidal anti-inflammatory agents in the wards.

Communication

Frequent, consistent and honest communication between anaesthesiologist and surgeon is the one factor that ensures the best possible patient outcomes in respect of recognition and prevention of complications, and dealing with them as they occur. Interruption of pneumoperitoneum, limitations of insufflation pressure, adequate muscle relaxation or changes in patient position should be part of the joint responsibility of surgeon and anaesthetist.

Laparoscopic surgery requires a knowledgeable team, which includes all the theatre staff from the scrub team to the anaesthetic assistant, to optimise outcomes in these patients.

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