Anesthetic Implications of Laparoscopic Surgery

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(Received February 6, 1998; accepted February 15, 1999)

Minimally invasive therapy aims to minimize the trauma of any interventional process but still achieve a satisfactory therapeutic result. The development of "critical pathways," rapid mobilization and early feeding have contributed towards the goal of shorter hospital stay. This concept has been extended to include laparoscopic cholecystectomy and hernia repair. Reports have been published confirming the safety of same day discharge for the majority of patients. However, we would caution against overenthusiastic ambulatory laparoscopic cholecystectomy on the rational but unproven assumption that early discharge will lead to occasional delays in diagnosis and management of postoperative complications.

Intraoperative complications of laparoscopic surgery are mostly due to traumatic injuries sustained during blind trocar insertion and physiologic changes associated with patient positioning and pneumoperitoneum creation. General anesthesia and controlled ventilation comprise the accepted anesthetic technique to reduce the increase in PaCO₂. Investigators have recently documented the cardiopulmonary compromise associated with upper abdominal laparoscopic surgery, and particular emphasis is placed on careful perioperative monitoring of ASA III-IV patients during insufflation. Setting limits on the inflationary pressure is advised in these patients. Anesthesiologists must maintain a high index of suspicion for complications such as gas embolism, extraperitoneal insufflation and surgical emphysema, pneumothorax and pneumomediastinum.

Postoperative nausea and vomiting are among the most common and distressing symptoms after laparoscopic surgery. A highly potent and selective 5-HT3 receptor antagonist, ondansetron, has proven to be an effective oral and IV prophylaxis against postoperative emesis in preliminary studies. Opioids remain an important component of the anesthetic technique, although the introduction of newer potent NSAIDs may diminish their use. A preoperative multimodal analgesic regimen involving skin infiltration with local anesthesia. NSAIDs to attenuate peripheral pain and opioids for central pain may reduce postoperative discomfort and expedite patient recovery/discharge. There is no conclusive evidence to demonstrate clinically significant effects of nitrous oxide on surgical conditions during laparoscopic cholecystectomy or on the incidence of postoperative emesis. Laparoscopic cholecystectomy has proven to be a major advance in the treatment of patients with symptomatic gallbladder disease.

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b Abbreviations: FVC, forced vital capacity; FEV₁, forced expiratory volume in 1 second; FEF, forced expiratory flow; LA, laparoscopic appendectomy; OA, open appendectomy; CT, computed tomography; IAP, intra-abdominal pressure; ETCO₂, end-tidal CO₂; ITP, intra-thoracic pressure; CVP, central venous pressure; CO₂ output; FRC, functional residual capacity; PaCO₂, partial pressure arterial carbon dioxide; PvCO₂, mixed venous CO₂ tension; Q̇, cardiac output; V̇Ȧ, alveolar ventilation; PEP, pre-ejection period; LVET, left ventricular ejection time.
Table 1. Laparoscopic surgical procedures.

**Intra-abdominal:**

Therapeutic:
- Cholecystectomy
- Vagotomy
- Hiatus hernia repair
- Diaphragmatic hernia repair
- Appendectomy
- Colectomy
- Inguinal hernia repair

**Gynecologic:**

Therapeutic:
- Ectopic pregnancy
- Ovaries
- Fallopian tubes
- Hysterectomy

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**INTRODUCTION**

The historical milestones in the evolution of laparoscopic surgery have been comprehensively detailed by Gaskin et al. [1]. For the most part, gynecologists developed the instrumentation, operating principles and techniques of operative laparoscopy. The apparent lack of attention given to laparoscopy by general surgeons since its development in the early part of this century was largely due to its perceived role as a diagnostic tool rather than a therapeutic one. The advent of laparoscopic cholecystectomy was the catalyst that aroused the interest of general surgeons worldwide in laparoscopy and closed abdominal surgery [2-5]. The scope of minimal access abdominal, thoracic and pelvic surgery through the laparoscope has been so expanded that it is likely to be applicable to the majority of functional gastrointestinal, thoracic and gynecologic procedures (Table 1).

The publication by Steptoe [6] in 1967 about the technique of laparoscopy for use in gynecological practice was adopted widely by practitioners and was followed by several reviews outlining the anesthetic considerations for these procedures [7-8]. The creation of a pneumoperitoneum by insufflation of the abdominal cavity with carbon dioxide (CO₂) and the assumption of the lithotomy position with a steep head-down (Trendelenburg) position had several potential hemodynamic and respiratory consequences. However, these gynecologic procedures were generally of short duration and were performed on young, otherwise healthy female patients. Changes in hemodynamic and respiratory function associated with intraperitoneal CO₂ insufflation during these short procedures was investigated extensively and found to be relatively insignificant.

New intra-abdominal laparoscopic surgical techniques have been developed, performed and advocated for older patients who may have co-existing cardiac and/or pulmonary disease [9]. These laparoscopic procedures may involve changes in patient position from Trendelenburg to reverse Trendelenburg and require longer periods of intraperitoneal CO₂ insufflation compared with gynecologic procedures.

This review will incorporate data on the physiologic consequences of creation of pneumoperitoneum, which were derived from early studies of gynecologic procedures, and will focus on the unique anesthetic considerations involved in laparoscopic general surgical procedures.
Table 2. Laparoscopic cholecystectomy comparison with traditional open cholecystectomy.

- Minimizes the abdominal incision
- Preserves diaphragmatic function

Potential benefits:
- Reduced adverse events
- Pulmonary function preserved
- Less postoperative ileus
- Early ambulation
- Economic benefits
  - Shorter hospital stay
  - Early return to work and normal activities

LAPAROSCOPIC SURGICAL PROCEDURES

Therapeutic intra-abdominal cholecystectomy

There are approximately 500,000 cholecystectomies performed annually in the United States [10]. For decades, these procedures were performed through a right upper quadrant incision, which proved to be a safe and efficient means of managing cholelithiasis. Although the overall reported mortality for open cholecystectomy in some series was less than 0.1 percent, surgery for complications of gall stones in the elderly may be associated with mortality of up to 10 percent [11]. Most patients experience significant postoperative impairment of pulmonary function, pain, discomfort, ileus, and require prolonged convalescence. The major source of complications in the open cholecystectomy procedure is the abdominal incision [12]. Upper abdominal procedures, including open cholecystectomy, produce significant impairment of pulmonary mechanics, ventilation and defense mechanisms independent of the effects of general anesthesia [13].

Laparoscopic cholecystectomy has rapidly emerged as a popular alternative to traditional laparotomy and cholecystectomy in the management of cholelithiasis [14]. The technique was first described in France by Phillipe Mouret in 1988 (personal communication). In 1988, it was reported in the literature by Perissat et al., [15] and was refined and popularized in the United States by Reddick and Olsen [16]. Laparoscopic cholecystectomy combines the benefit of completely removing the gall bladder with the advantages of shorter hospital stay, more rapid return to normal activities, less pain associated with the small, limited incisions and less postoperative ileus compared to the open laparotomy technique [17-19] (Table 2).

The major benefits of laparoscopic cholecystectomy are thought to result from avoidance of the large abdominal incision. Holohan [20] claimed that the overall adverse event rate of 22.4 percent associated with open cholecystectomy was more than six times higher than the rate reported in 3,225 laparoscopic cholecystectomies compiled from 11 other studies. The most comprehensive assessment of laparoscopic cholecystectomy has been undertaken by Meyers et al. [21] under the auspices of The Southern Surgeons Club in a prospective study of 1,518 patients distributed equally between academic and community hospitals. The 5.1 percent complication rate included seven patients with bile duct injuries. The most common complication was superficial infection at the site of insertion of the umbilical trocar. Based on their analysis of the risk/benefit ratio, the preference of experienced surgeons for the laparoscopic technique was highlighted by the fact that during the study period, the 59 participating surgeons performed only 12 percent of cholecystectomies by the traditional open technique.
There have been but few prospective, randomized studies comparing the laparoscopic and the open cholecystectomy procedures. In a prospective, non-randomized study of 16 patients undergoing open cholecystectomy and 20 patients undergoing laparoscopic cholecystectomy, Frazee et al. [22] reported postoperative forced vital capacity (FVC) of 52 percent, forced expiratory volume in one second (FEV\(_1\)) of 53 percent, and forced expiratory flow (FEF) of 53 percent of baseline values for patients undergoing open cholecystectomies, compared with FVC, FEV\(_1\) and FEF of 73 percent, 72 percent and 81 percent, respectively, for those patients undergoing laparoscopic cholecystectomies. In a prospective randomized study involving 20 patients, Putensen-Himmer et al. [23] noted that in the early postoperative period, lung volumes, including functional residual capacity, decreased less and returned sooner to preoperative levels after laparoscopic cholecystectomy compared with open subcostal laparatomic cholecystectomy. The location and extent of abdominal incision has been shown to influence the degree of postoperative pulmonary impairment [24]. Rademaker et al. [25] compared the effects of cholecystectomy by subcostal incision to those of laparoscopy on lung function and endocrine metabolic responses. The effects of thoracic epidural analgesia for laparoscopic cholecystectomy were also studied. Pulmonary function was significantly better after laparoscopic than after cholecystectomy via the subcostal technique. Thoracic epidural anesthesia decreased postoperative pain and possibly attenuated the metabolic endocrine responses but did not improve lung function after laparoscopic cholecystectomy. Frazee et al. [22] claimed that the 20 to 25 percent improvement in FEV\(_1\), FVC and FEF in patients undergoing laparoscopic cholecystectomy was due to minimal abdominal wall disruption, leading to less postoperative pain. In support of this, the differences in pulmonary function were present despite longer anesthetic and operating times in the laparoscopic group.

**Vagotomy:** The surgical treatment of choice for chronic duodenal ulceration resistant to medical treatment includes highly selective vagotomy with preservation of the antropyloric innervation and motility [26]. Katkhouda and Moulier [27] proposed a modified laparoscopic right truncal vagotomy and anterior lesser curvature seromyotomy. The technique involves general anesthesia, 12 to 14 mm Hg pneumoperitoneum creation, an umbilical laparoscope insertion site and four additional trocar insertions. In the initial series of 10 patients, the mean length of surgery was 60 minutes, and no morbidity was reported. All patients were discharged within five days after surgery.

**Hiatus hernia repair:** Large hiatal hernias (sliding, paraesophageal and mixed) may be encountered, especially in the elderly. A technique of laparoscopic mobilization of the abdominal esophagus and esophagogastric junction has enabled successful antireflux surgery to be undertaken [28]. Crural repair is an essential part of this procedure and is usually accompanied by a total fundoplication. Cuschieri et al. [29] developed a laparoscopic technique that reproduced the essential components of the standard surgical management. The operative technique involved general anesthesia, pneumoperitoneum creation, telescope insertion 2.5 cm to the left and above the umbilicus and four additional upper abdominal cannulae insertion sites.

The average operating time was three hours in the initial series of eight elderly patients [28]. Complications encountered included transient cervical surgical emphysema in three patients, left pneumothorax in one patient and transient dysphagia in one patient. The surgical emphysema was attributed to CO\(_2\) migration up the mediastinum during the dissection and was considered to be of no significance. The apical pneumothorax occurred in the absence of obvious damage to the pleura. A chest drain was inserted in the recovery room.

**Diaphragmatic hernia repair:** Blunt diaphragmatic rupture is an uncommon injury, occurring in only four to eight percent of patients undergoing laparotomy for blunt thoraco-abdominal trauma [30]. Most series report a predominance of left-sided versus right-
sided injury. Suspicions of ruptured diaphragm in the preoperative period should be entertained by the presence of pleural effusion, elevation of the hemidiaphragm, irregularity of the diaphragmatic contour and evidence of solid or hollow viscus in the chest. The location of a nasogastric tube above the diaphragm is pathognomonic for left diaphragmatic rupture when present. Diagnosis of right-sided injury is particularly difficult because the liver has a smooth contour not unlike the diaphragm. Confirmatory tests for the detection of diaphragmatic rupture include diaphragm fluoroscopy, peritoneal lavage, gastrointestinal contrast studies, computed tomography (CT) scans and thoracoscopy [31].

Falcone et al. [32] were the first to report the laparoscopic diagnosis of a traumatic right-sided diaphragmatic rupture with herniation of the liver. Campos and Sipes [33] reported successful laparoscopy with repair of an iatrogenically acquired diaphragmatic hernia. No respiratory or diaphragmatic complications were observed during the case. Notwithstanding the absence of details concerning the anesthetic management and patient monitoring, the authors went on to suggest that the fear of creating an inadvertent pneumothorax should not preclude the use of the new advances in minimally invasive surgery.

Adamthwaite [34] reported a series of 10 patients with penetrating and blunt trauma in whom laparoscopy was used to visualize the peritoneal side of the diaphragm. The procedures were performed under general or regional anesthesia, depending on the general condition of the patient. All eight patients with visualized diaphragmatic lesions on laparoscopy underwent surgical repair, and no further interventions followed in the two patients with intact diaphragms. There were no reported intra- or post-operative complications.

Appendectomy: Paterson-Brown highlighted the role of laparoscopy in the management of patients with acute abdominal pathology in a recent comprehensive review [35]. Sugerbaker et al. [36] were the first to suggest that laparoscopy might have a role to play in the management of these conditions when they reported a series of patients with acute abdominal pain of unknown origin in whom pre-laparotomy laparoscopy allowed a diagnosis to be made in 96 percent of patients, preventing many of them going on to an unnecessary laparotomy. Subsequent studies confirmed the value of laparoscopy in the specific problems such as right iliac fossa and pelvic pain [37]. Studies have shown that the rate of unnecessary appendectomies could be reduced, especially in women [38].

Nowzaradan et al. [39] claimed that a diagnostic laparoscopy offered a safe, early and accurate (95 percent) diagnosis, thus eliminating a period of observation and empirical treatment. In the absence of appendiceal pathology, a laparoscopic diagnosis obviated the need for unnecessary laparotomy in 20 to 30 percent of cases and, thus, eliminated the complications of laparotomy and its sequelae. In the 35 patients who underwent laparoscopic appendectomy (LA), there were no intra-abdominal injuries, blood loss was minimal and no postoperative complications, wound infections or incisional hernias were recorded. The authors cautioned, however, that patients with symptoms suggesting that the appendix is perforated are not appropriate candidates for laparoscopic treatment and should be managed with formal laparotomy.

The efficacy of laparoscopic appendectomy was the subject of recent editorial comment [40]. Traditional appendectomy is still complicated by a small, albeit significant, incidence of wound infection, postoperative pelvic abscesses and adhesions. Early laparoscopic experience suggests that patients have improved cosmesis, a decrease in morbidity, a reduction in wound pain, a shortened hospital stay and a quicker return to normal activities [41]. However, no prospective randomized trials performed by surgeons of comparable experience comparing laparoscopic with open appendicectomy have yet been reported. Gilchrist et al. [42] assessed the value of laparoscopic appendectomy in childhood by prospectively comparing 14 non-randomized laparoscopic procedures with 50 open appendectomies (OA) over a six-month period in a single institution. A three-puncture LA
technique was used. Patients in the LA group spent significantly fewer days in hospital and returned to unrestricted activities faster than patients in the OA group. However, the LA is approximately $1,000 more expensive than the OA, the differences being attributed to the disposable supplies necessary for the procedure.

**Colectomy**: The development of laparoscopic procedures for colon resection involved not only considerable technical refinements but also the facilities to remove a malignant tumor in a surgically acceptable manner compared with standard open colectomy. Schlinskert [43] described a laparoscopic technique to assist in the performance of a right hemicolectomy. The technique involved general anesthesia, supine position with legs in stirrups and CO₂ pneumoperitoneum. There were three 5 mm trocar sites, two 10 mm trocar sites, and a small incision was required in addition for removal of the surgical specimen.

Monson et al. [44] prospectively evaluated laparoscopic colectomy in 40 patients requiring elective colonic resections, mainly for malignant disease. Thirty-three of the 40 patients studied had successful completion of the laparoscopic colectomy. Seven patients required conversion to conventional open laparotomy. The notable features of the laparoscopic procedure were low morbidity in terms of chest and wound infections with early mobilization and discharge from hospital. For right-sided colonic lesions, some form of abdominal incision was required to retrieve the resected specimen.

**Inguinal hernia repair**: Inguinal hernias are being repaired using a laparoscopic technique in several centers [1]. The approach appears more applicable to indirect hernias and is being managed by a ring closure accomplished either with a stapler or with intra-abdominal suturing. The direct hernia repair appears more challenging and requires the placement of mesh and intra-abdominal suture technique that, to date, is cumbersome and time consuming. The objectives of the procedure are to reduce the contents and the sac and to repair the defect.

The laparoscopic abdominal approach to inguinal hernia repair was advocated by Schultz et al. [45]. Proponents claim that the avoidance of incisions means that the traditional complications of groin induration and ilio-inguinal neuropathy associated with the surgical procedure are avoided, and early return to full physical activity is assured [46].

The considerations for laparoscopic repair of inguinal hernias are, however, different from those of other laparoscopic procedures such as cholecystectomy and appendectomy. Many traditional inguinal hernia repairs in North America are performed with a local anesthetic technique and involve small surgical incisions. What may make laparoscopic inguinal hernia repairs less attractive to patients is that general anesthesia is required and that, when the lengths of the three incisions for laparoscopy are compared with the one incision for traditional surgical repair, the length of the incisions may be comparable. Also, concerns about possible recurrences may limit the application of the laparoscopic technique.

**Intra-abdominal diagnostic**

Jacobeus, from Stockholm, was the first to report in 1910 the laparoscopic inspection of the peritoneum, pleura and pericardium in humans [1]. However, since its introduction in first decade of this century, the use of laparoscopy by general surgeons has been sporadic. In the past 15 years or so, enthusiastic surgical centers have awoken to the diagnostic potential of laparoscopy and have identified specific general surgical applications. These have been primarily, though not exclusively in the elective assessment of patients with hepatobiliary disease, intra-abdominal masses and malignancies. However, the more recent applications of laparoscopy in the management of acute abdominal conditions has been the subject of considerable controversy.
Diagnostic laparoscopy allows direct observation of many intra-abdominal structures and surfaces (Table 3). The abdominal wall and diaphragmatic peritoneal surfaces may be visualized over most of their areas. Pneumoperitoneum creation allows the identification of hernias and abdominal wall defects. Intra-abdominal viscera can be examined, to a greater or lesser degree, depending on body habitus, location of the organ and expertise of the endoscopist. Low complication rates and high diagnostic accuracy have been claimed for laparoscopy used in the staging of primary intra-abdominal tumors, the evaluation of metastatic disease and the diagnosis of jaundice and abdominal pain [47].

Laparoscopy has proved to be of value in assessing the dissemination of intra-abdominal malignancies in patients with esophageal, gastric, biliary and pancreatic pathology. Watt et al. [48] reported that laparoscopy was significantly more sensitive and more accurate than either ultrasound or CT in detecting hepatic and peritoneal metastases in patients with esophageal carcinoma. Shimi et al. [49] claimed that laparoscopy was superior than ultrasound or CT in the detection of small hepatic deposits and peritoneal deposits in patients with pancreatic carcinoma. This diagnostic modality avoided
unnecessary laparotomy in patients with advanced disease, while permitting visualization of the tumor and procurement of biopsy material for histological confirmation of the diagnosis.

The use of staging laparoscopy is well established for patients with malignant lesions of the upper gastrointestinal tract (i.e., distal esophagus, stomach, bile ducts and pancreas), where alternative means of palliation exist in cases of advanced disease. This is not true, at present, for colorectal malignant neoplasms; resection or bypass surgery is considered the best palliation for advanced colorectal malignant neoplasms [50]. Laparoscopic diagnosis of liver disease may produce a diagnostic yield up to 95 percent. This high yield results from the usefulness of biopsy under direct vision of the liver surface in the investigation of patients with jaundice or hepatomegaly [51]. Cholestasis in children warrants the differentiation between hepatitis (medical therapy) and biliary atresia (operative intervention). While ultrasonography may rule out biliary atresia, there a number of cases in which laparoscopy will be indicated to make the diagnosis [52].

The practice of contralateral exploration of children with inguinal hernias was begun in the early 1950s by Duckett [53]. Lobe and Schropp [54] undertook a laparoscopic inguinal exploration in 22 consecutive pediatric patients to assess the value of this technique in detecting the presence or absence of occult inguinal hernias on the asymptomatic side of patients with unilateral disease. The laparoscopic inguinal exploration was 96 percent accurate in this initial evaluation. The adoption of this approach to the assessment of the asymptomatic contralateral side in infants with unilateral hernias may eliminate many inguinal operations and the complications associated with unnecessary manipulation of delicate cord structures. In addition, the role of laparoscopy in the undescended testes in the pediatric population has been recently highlighted [55]. Laparoscopy was reported to be a safe procedure that allowed accurate diagnosis, facilitated the location of the testis and guided the planning and timing of subsequent orchidopexy.

The detection of intra-abdominal bleeding following major trauma may be difficult in the context of obscure physical signs with impaired level of consciousness, alcohol or drug ingestion and unexplained hypotension or equivocal signs on physical examination in the conscious patient. The introduction of peritoneal lavage improved the diagnosis of intra-abdominal trauma. Subsequent experience with this test in patients with blunt abdominal trauma has shown that not every positive lavage requires exploration [56]. The incidence of unnecessary diagnostic laparotomies in these cases has ranged from 15 to 20 percent. Wood et al. [57] developed a mini-laparoscope for use at the bedside, in the emergency room or intensive care unit. The procedure was performed with local anesthesia and intravenous sedation if required. Berci et al. [58] claimed that emergent or urgent laparoscopy in blunt abdominal trauma with obscured physical signs reduced the number of unnecessary abdominal explorations. Cuschieri et al. [59], in a prospective randomized multicenter study of hemodynamically-stable trauma victims with positive physical signs, reported that the predictive value of a positive mini-laparoscopic examination was 92 percent as opposed to a positive predictive value of 72 percent for peritoneal lavage.

**Gynecologic**

In recent years, uses for the laparoscope in gynecology have expanded dramatically from diagnosis and tubal stentization to treatment of ectopic pregnancy and ovarian neoplasms. Grimes [60] recently provided a comprehensive review and critique of of the evidence supporting the use of operative laparoscopy for a number of expanded indications in gynecology, including ectopic pregnancy and tubo-ovarian pathology. The literature concerning the expanded indications for operative laparoscopy consists primarily of descriptive studies that claim reduced hospitalization, faster recovery and lower costs.
However, very few prospective randomized controlled trials or analytical studies have been reported; those that have been reported have methodological shortcomings, including low power.

Ectopic pregnancy has been the most thoroughly studied indication for operative laparoscopy. Two groups of investigators have evaluated management of ectopic pregnancy in randomized controlled trials. In a study of 60 patients with unruptured tubal pregnancies, Vermes et al. [61] randomized half to undergo salpingostomy by laparoscopy and half by laparotomy. The complication rate was similar in both groups, but the group having laparoscopy had shorter hospital stays and recuperation. In a similar study by Lundorff et al. [62], 73 patients underwent a second laparoscopy to evaluate adhesion formation after treatment for ectopic pregnancy. In the group having prior laparoscopic treatment, adhesions involving the ipsilateral tube were less common than in the group having laparotomy.

Cohort and case series studies report short operating times, low complication rates, short hospital stays and early return to normal activities with the use of laparoscopy in the management of diverse conditions including ruptured or recurrent ectopic pregnancies, ovarian cysts, pelvic adhesions, torsion of fallopian tubes, etc. [63-66]. A prospective study to determine the feasibility and effectiveness of laparoscopically-assisted hysterectomy was undertaken by Maher et al. [67]. The procedure involved uterine manipulation by vaginal instrumentation, three or four abdominal trocar puncture sites and bipolar-diathermy to secure vascular pedicles. The cardinal and uterosacral ligaments were divided and the uterus was removed through the vagina (operating time was 90 to 220 minutes and the blood loss was 30 to 100 ml). The authors claimed that laparoscopically-assisted hysterectomy may be of value when adenexal or uterine abnormalities are present and vaginal hysterectomy is technically difficult or contraindicated. Nezhat et al. [68] reported a seven-hour duration, laparoscopically-assisted radical hysterectomy with para-aortic and pelvic node dissection.

SPECIAL CONSIDERATIONS

Surgical technique

The operative technique for laparoscopic surgery usually involves the intraperitoneal insufflation of CO₂ through a Veress needle inserted into a small infra-umbilical incision, with the patient in a 15- to-20 degree Trendelenburg position [20]. An electronic variable-flow insufflator terminates flow when a preset intra-abdominal pressure of 12 to 15 mm Hg has been reached. A cannula then is inserted in place of the needle to provide and maintain insufflation adequate for surgery. A video laparoscope is inserted through the cannula, and the operative field is visualized by high resolution television camera and monitor systems.

The number and location of additional cannulae vary depending on the surgical procedure. Also, the patient’s position following pneumoperitoneum creation will depend on surgical requirements. In the case of laparoscopic cholecystectomy, the diseased gallbladder is removed, following surgical dissection, by means of instruments introduced through cannulae via three additional small (5 to 11 mm) skin incisions. These, cannulae or trocars are inserted under direct vision for placement and control of the instruments required to dissect the gallbladder. The sites of trocar and cannulae insertion may vary, but they usually include one to the right of midline to avoid injury to the falciform ligament, and two other sites in the right upper quadrant. The patient’s position is then changed to steep reverse Trendelenburg, with left lateral tilt, to facilitate retraction of the gall bladder fundus and to minimize the diaphragmatic dysfunction associated with the induced pneumoperitoneum. The cystic duct and cystic artery are identified and clamped. The video
Table 4. Laparoscopic cholecystectomy

**Established indications for surgery:**
- Cholelithiasis
- Chronic cholecystitis

**Controversial indications/relative contraindications:**
- Acute cholecystitis
- Pregnancy
- Previous abdominal surgery (adhesions)
- Morbid obesity
- Cardiopulmonary disease

A laparoscope is then moved to an upper midline abdominal position to allow visualization of the gallbladder as it is removed through the periumbilical cannula by means of a claw forceps or extractor.

In the case of laparoscopic assisted colectomy, a number of trocars are inserted to enable passage of specialized grasping instruments and endoscopic staplers. For right-sided colonic resections, some form of abdominal incision is still required to retrieve the resected specimen. Although in some instances selected colorectal specimens may be removed from the left side via a transanal route, most practitioners remove the specimen through a small suprapubic incision, especially in patients with malignant disease [44].

**Indications/contraindications**

Indications for laparoscopic cholecystectomy are the same as for the open procedure, i.e., symptomatic cholelithiasis and chronic cholecystitis. Early contraindications to the laparoscopic technique included the presence of large stones or common bile duct stones, evidence of acute inflammation or pregnancy [69] (Table 4).

The indications for the laparoscopic technique have become more liberal recently after case reports confirmed its efficacy and safety in patients with acute cholecystitis [70] and during pregnancy [71]. Laparoscopic cholecystectomy has become the routine procedure both in academic centers and in community hospitals [72]. Dubois et al. [9] claim that laparoscopic surgery causes minimal trauma and stress, and is the procedure of choice for high operative risk patients, especially those with cardiac and respiratory disease. In light of the low morbidity rate associated with laparoscopic surgery in patients over 80 years of age, it has been advocated as the technique of choice in the elderly. Martin et al. [73], in a report describing 165 consecutive patients with gallstones treated in the same institution, claimed that the experience from their "all comers" policy would indicate that the laparoscopic technique could be safely extended from selected patients to the generality of patients with gallstones who present urgently or electively.

The presence of pre-existing lung disease has been considered neither a relative, nor an absolute contraindication for laparoscopic cholecystectomy. However, recent case reports [74] and studies [75] have documented profound intraoperative hypoxemia and respiratory acidosis in patients with pre-existing chronic obstructive and restrictive lung disease. Some authors have claimed that the obese patient benefits from a laparoscopic cholecystectomy technique because of the reduced risk of wound infection and the ease of visualization of the biliary tree compared with the a traditional upper abdominal incision [76]. In contrast, Monson et al. [44] are convinced that, unlike laparoscopic cholecystectomy, obesity is an important obstacle to laparoscopic colectomy because of difficulties in colonic mobilization and identification of major blood vessels. Furthermore, a bulky
greater omentum may present technical problems around the transverse colon and prominent, and fatty appendices epiploicae may make colonic division more difficult.

Conversion to traditional open procedures

The evolving role of laparoscopic cholecystectomy in the management of gall bladder disease has been the subject of extensive recent editorial comment [77-79]. The conversion
rates from laparoscopic to open cholecystectomy varied from 1.0 percent to 6.9 percent in five recently published series [80-84]. Experience from several institutions suggests that the incidence of common bile duct injuries may be higher with the laparoscopic procedure, and conversion to open cholecystectomy was usually caused by difficulty in identifying and mobilizing the cystic duct. Other causes include suspected or confirmed common bile duct injury, uncontrolled bleeding from the cystic artery, acute inflammatory changes and stones present in the common bile duct.

Concerns have been expressed in the surgical literature concerning bile duct injuries detected during and following laparoscopic cholecystectomy [85-86]. Bile duct injuries associated with laparoscopic cholecystectomy have been linked to surgical inexperience and the lack of operative cholangiography. Case reports have described transection of the common bile duct, obstruction of the duct with metal clips and overzealous stripping of the ducts leading to necrosis. Failure to convert to open cholecystectomy in the face of anatomical uncertainty or technical difficulty has been proposed as a contributing factor to bile duct injuries.

Different indications for abandoning laparoscopic-assisted colonic surgery were advanced by Monson et al. [44]. In this series, of the 40 colonic resections attempted with the laparoscopic technique, 33 were completed successfully. Conversion to traditional surgical technique was necessary because of tumor attachment and concern for the safety of vital structures such as the ureter and aorta. Data from series describing new laparoscopic applications, i.e., appendectomy, suggest that conversion to traditional open procedures are more common in the early “learning curve” and that, with experience, the procedure can safely be accomplished [41].

The anesthesia literature is conspicuous by the absence of data concerning anesthesia-related complications necessitating conversion from a laparoscopic to traditional open surgical procedure. Apart from isolated case reports and letters describing the uneventful anesthetic management of such cases [87-89], we reported the first case of profound and sustained intraoperative hypoxemia associated with high peak airway pressures that necessitated conversion from laparoscopic to traditional open cholecystectomy. [74].

**PHYSIOLOGIC CHANGES AND COMPLICATIONS**

Significant data have been accumulated regarding complications associated with laparoscopy. The complications unique to laparoscopic cholecystectomy, recently reviewed by Ponsky, include: injury to tissues during the intraperitoneal insertion of the trocar; untoward physiologic changes associated with creation of pneumoperitoneum while the patient is in the steep head-up or head-down position; and systemic absorption of the intraperitoneally insufflated CO₂ [90] (Figure 1).

**Trocar insertion**

The establishment of a pneumoperitoneum during laparoscopy is essential for most laparoscopists before a trocar and laparoscope can be introduced into the peritoneal cavity. To achieve a pneumoperitoneum, a Veress needle is introduced into the peritoneal cavity, and CO₂ gas is insufflated. Injuries have been reported to occur as the Veress needle or trocar are introduced blindly through the abdominal wall prior to insertion of the laparoscope. Such injuries have included bleeding from abdominal wall vessels, gastrointestinal tract perforations, hepatic and splenic tears, major vascular trauma, avulsion of adhesions, omental disruption and herniation at the trocar insertion site [90]. A “Hassan” minilaparotomy technique has been advocated for pneumoperitoneum creation to avoid injuries associated with blind Veress needle and trocar insertion [91].
Trendelenburg position

In the 1860s, Friedrich Trendelenburg, a German urologic surgeon, popularized the high pelvic posture that still bears his name [92]. In gynecologic and during the initial stages of laparoscopic surgical procedures, the patient is normally placed in a 10 to 20-degree Trendelenburg position in order to keep the small bowel and colon out of the pelvis and to minimize complications associated with blind trocar insertion.

Gravity has profound effects on the cardiovascular and pulmonary systems. The physiologic effects of the head-down position in euvoletic patients have been reviewed recently by Wilcox and Vandam [93]. The head-up position improves diaphragmatic function and respiratory status, while the head-down position favors venous return and, thus, improves cardiac output [94]. The cardiovascular changes associated with Trendelenburg position may be influenced by the extent of the head-down tilt, the patient’s age, intravascular volume status, associated cardiac disease, anesthetic drugs administered and ventilation techniques.

Pulmonary function changes associated with the head-down position will depend on the patient’s age, weight and preoperative lung function, the degree of head-down tilt, the anesthetic agents used and the intraoperative ventilatory techniques. The Trendelenburg position reduces vital capacity because of the increased weight of the abdominal viscera on the diaphragm [95]. These changes may be more marked in obese, elderly or debilitated patients, and may be worsened by placement of surgical packs and retractor in the upper abdomen. The potential for inadvertent right mainstem bronchial intubation and hypoxemia associated with Trendelenburg positioning was highlighted by Wilcox and Vandam [93]. The mechanism proposed is that the endotracheal tube, firmly secured at its proximal end to the mandible, does not always move along with the trachea as the diaphragm displaces the lung and carinal cephalad [96].

Creation of pneumoperitoneum

The most frequent surgical complications are associated with creation of the initial pneumoperitoneum [97]. These include hemorrhage, bowel perforation, subcutaneous or mediastinal emphysema, pneumothorax, hypoxemia, hypotension, CO$_2$ embolism, cardiovascular collapse and cardiac dysrhythmias. Complications associated with the laparoscopic procedure (i.e., hemorrhage, bile duct injury, perihilar collections, infection) are similar to those that may be encountered during traditional open cholecystectomy, although the frequency with which they occur may differ [20]. Perforation of the gallbladder itself, although not usually significant during the performance of open cholecystectomy, may preclude successful completion of the laparoscopic approach.

Pneumoperitoneum creation involves the intraperitoneal insufflation of CO$_2$ through a Veress needle while the patient is in a 15- to 20-degree Trendelenburg position. The potential difficulties that may be encountered during creation of pneumoperitoneum are outlined below.

Technical difficulties: Extraperitoneal insufflation of CO$_2$ is one of the most common complications of laparoscopy. The incidence of this complication has been reported to vary from 0.4 to 2 percent [98]. Such extraperitoneal insufflation may cause subcutaneous or retroperitoneal emphysema, prolonging or causing the abandonment of surgery. Subcutaneous emphysema may follow if the tip of the Veress needle does not penetrate deeply enough to enter the peritoneal cavity prior to insufflation of gas. This may cause the insufflating gas to accumulate in the subcutaneous tissue or between the fascia and the peritoneum. Lew et al. [99] reported extensive subcutaneous emphysema that involved the neck, chest and abdomen and extended to the groin. The mechanism postulated in this case report was subcutaneous insufflation of CO$_2$ from a poorly stabilized Veress needle.
**Pneumomediastinum and pneumothorax:** Pneumomediastinum and pneumothorax have been reported to occur subsequent to pneumoperitoneum creation. The postulated mechanisms include passage of insufflating gas through weak points or defects in the diaphragm. In support of this contention, there are several reports in the literature of catastrophic pneumothorax [100]. Pneumothoraces have been reported in association with subcutaneous emphysema and pneumomediastinum [101]. A case of isolated tension pneumothorax has been reported during laparoscopic cholecystectomy following trocar insertion and intraperitoneal CO₂ insufflation [102]. A congenital defect of the diaphragm (patent pleuroperitoneal canal) through which the insufflated gas passes into the thoracic cavity has been suggested as the underlying mechanism [8]. Alternatively, a ruptured bleb or bulla could have produced the tension pneumothorax independent of the pneumoperitoneum.

Shah and Ramakantan [103] suggested an alternative mechanism for the development of pneumomediastinum in association with pneumoperitoneum. If the Veress needle is introduced too deeply into the abdominal cavity, the resulting pneumoretroperitoneum will allow mediastinal passage of gas through the aortic and esophageal diaphragmatic hiatus. In this instance, neither the pneumoretroperitoneum nor pneumomediastinum were associated with significant clinical consequences in most patients. Herrera et al. [104] reported a case of pneumopericardium in addition to pneumomediastinum and subcutaneous emphysema after laparoscopy for liver biopsy.

Undetected pneumothorax and pneumomediastinum can be life threatening. Subcutaneous emphysema of the neck, chest wall and face should alert the anesthesiologist to the possibility of such associated complications. As soon as this possibility is suspected, a chest radiograph should be obtained to diagnose or rule out a pneumomediastinum or pneumothorax. If there is clinical evidence of a tension pneumothorax, chest tube decompression is indicated before obtaining a chest radiograph.

**Cardiovascular effects:** The initial use of gynecologic laparoscopy was associated with generation of intra-abdominal pressures (IAP) of up to 40 mm Hg (55 cm H₂O). Modern laparoscopic surgery technology employs an electronic variable-flow insufflator, that automatically terminates flow when a preset IAP of 12 to 15 mm Hg is reached. Despite the relatively low IAP achieved, the volume of gas insufflated may exceed 50 liters because intra-abdominal gas may quickly escape through the multiple trocar/cannulae puncture sites.

The extent of the cardiovascular changes associated with creation of pneumoperitoneum will depend on the intra-abdominal pressure attained, the volume of CO₂ absorbed, the patient's intravascular volume, the ventilatory technique, surgical conditions and anesthetic agents employed. In a series of 13 otherwise healthy patients, Cunningham et al. [105] claimed that left ventricular function, as determined by transeosophageal echocardiographic estimation of ejection fraction, was preserved following CO₂ insufflation and patient position changes, despite variations in left ventricular loading conditions. However, CO₂ insufflation was associated with increases in left ventricular end-systolic wall stress, concomitant with increases in systemic arterial pressure. In addition, left ventricular end-diastolic pressure decreased following reverse Trendelenburg positioning. Left ventricular ejection fraction was maintained throughout the study period in this investigation of otherwise healthy patients. However, it might reasonably be speculated that the above changes in left ventricular loading conditions might have had deleterious consequences in a patient population with significant cardiovascular disease. Similar observations were made by Noirot et al. [106] after an observational study of 20 patients, free of cardiac disease, in whom an IAP of 14 mm Hg was maintained for 65 minutes. This IAP increase resulted in an increased systemic vascular resistance, a drop in cardiac index and a rise of mean arterial pressure. While right atrial pressure and pulmonary capillary wedge
pressure significantly decreased after tilting to the head-up position, they increased during peritoneal insufflation.

In a prospective, observational study of 16 otherwise healthy patients, Liu et al. [107] noted no significant cardiac output changes, despite an increased mean arterial pressure and end-tidal CO$_2$ (EtCO$_2$) during creation of pneumoperitoneum. Similarly, Marshall et al. [108] reported no significant changes in cardiac output in a series of anesthetized, spontaneously ventilating patients in whom the IAP was 15 to 20 cm H$_2$O (11 to 15 mmHg). Smith et al. [109] studied the cardiovascular effects of stepwise increases in IAP up to a maximum of 25 cm H$_2$O in anesthetized, mechanically ventilated patients. At an IAP of 25 cm H$_2$O, increases in airway pressure, intra-thoracic pressure (ITP), central venous pressure (CVP) and femoral venous pressure (FVP) were accompanied by hypertension, tachycardia and increased EtCO$_2$ tension. Kelman et al. [110] found that moderate increases of IAP (up to 25 cm H$_2$O) may be accompanied by an increased effective cardiac filling pressure (defined as CVP-ITP) and, therefore, (according to Starling’s law) by an increased cardiac output. When IAP was further increased to 40 cm H$_2$O, tachycardia, hypotension, reduced CVP and decreased cardiac output were observed. These changes were most marked in the horizontal compared with the head-down tilt position. The authors speculated that increased IAP has two opposite effects on the cardiovascular system: it forces blood out of the abdominal organs and inferior vena cava and into the

| Table 5. Intraoperative hypoxemia during laparoscopic surgery: differential diagnosis |
|---------------------------------|
| **Pre-existing conditions:**     |
| - Cardiopulmonary disease        |
| - Morbid obesity                 |
| **Hypoventilation:**             |
| - Patient position               |
| - Pneumoperitoneum.              |
| - Endotracheal tube obstruction   |
| - Inadequate ventilation: spontaneous/controlled |
| **Intrapulmonary shunting:**     |
| - Reduced FRC: (pneumoperitoneum-induced) |
| - Endobronchial intubation        |
| - Pneumothorax                    |
| - Emphysema: (mediastinum/subcutaneous) |
| - Bowel distension: (N$_2$O-induced) |
| - Pulmonary aspiration of gastric contents |
| **Reduced cardiac output:**      |
| - Hemorrhage: trocar injury       |
| - Inferior vena caval compression |
| - Dysrhythmias: hypercarbia/volatile anesthetic agents |
| - Myocardial depression: drug-induced/acidosis |
| - CO$_2$ venous embolism          |
| **Technical equipment failure:**  |
| - Circuit disconnect              |
| - Delivery of hypoxic mixture     |
central venous reservoir, while at the same time it increases peripheral blood pooling and, thus, tends to decrease the central blood volume.

The relative roles of the factors that contribute to changes in cardiac output may be difficult to separate, but the increased cardiac output at lower IAP may result from increased cardiac filling pressures, due partly to mechanical factors, and partly to constriction of capacitance vessels and hypercarbia-induced effects on cardiac efferent sympathetic activity [111]. Data reported by Beebe et al. [112] suggest that IAP increase with pneumoperitoneum cause venous stasis during laparoscopic cholecystectomy. Measures to reduce venous stasis, such as pneumatic, compressive stockings, may be indicated during these procedures.

In summary, the lack of critical experimental and clinical assessment of the physiologic changes associated with laparoscopic cholecystectomy and steep head-up position is in marked contrast to the systematic evaluation of changes during diagnostic laparoscopy performed in the late 1960s and early 1970s. This situation may have arisen because of the fulsome welcome given to laparoscopic cholecystectomy by general surgeons, health care providers and the medical/lay press. However, recent disquiet has been expressed concerning the seeming uncritical acclaim given to this new procedure [113].

**Respiratory function:** The limited available data suggest that the respiratory function changes occurring during laparoscopic cholecystectomy may differ from those reported during gynecologic laparoscopic procedures. Wittgen et al. [75] compared the ventilatory effects of laparoscopic cholecystectomy in 20 patients with normal cardiopulmonary status (ASA physical status 1) to the ventilatory effects in 10 patients with documented cardiac and pulmonary disease (ASA status 2 and 3). Although the patients without cardiopulmonary disease had increased end-tidal and PaCO₂ and decreased pH values following CO₂ insufflation, these changes were not statistically significant. Similarly, no significant changes occurred in minute volume and peak inspiratory pressure following CO₂ insufflation. In contrast, significant decreases in pHₐₚ and increases in PaCO₂ were observed in patients with cardio-pulmonary disease following CO₂ insufflation. These patients also had inspiratory pressures that were significantly higher than the baseline values following CO₂ insufflation.

Early reports of laparoscopy during halothane anesthesia emphasized the dangers of hypercarbia when patients were allowed to breathe spontaneously. Seed et al. [114] reported that the CO₂ output (VCO₂) increased from 135.4 ± 2.5 ml/min before, to 150.9 ± 6.9 ml/min after, the start of CO₂ insufflation. This increased VCO₂ was associated with end-tidal CO₂ concentrations which increased from 4.7 percent to 5.4 percent. Desmond and Gordon [115] observed tachypnea, increased minute ventilation and respiratory acidosis in a study of 10 patients spontaneously breathing nitrous oxide/oxygen and 0.5 to 1.0 percent halothane. The hypoventilation induced by the steep Trendelenburg position and the pneumoperitoneum-induced splinting of the diaphragm during halothane anesthesia were considered by the authors to be potentially hazardous.

Cunningham and Schlanger [74] reported a case of intraoperative hypoxemia complicating laparoscopy in an obese patient with sickle hemoglobinopathy. Some of the factors that might contribute to the development of intraoperative hypoxemia during laparoscopic surgery are listed in Table 5. A reduction in FRC relative to closing volume may be associated with the development of intraoperative atelectasis and intrapulmonary shunting. These changes may occur during general anesthesia because of a variety of factors: a) cephalad shift of the diaphragm associated with supine position [12]; b) loss of inspiratory muscle tone; c) appearance of end-expiratory muscle tone in the abdominal expiratory muscles; d) changes in intrathoracic blood volume associated with induction of anesthesia [116]; and e) influence of muscle relaxants on diaphragmatic excursion [117]. The
reduction in FRC associated with general anesthesia may be compounded by the CO₂-induced pneumoperitoneum during laparoscopic cholecystectomy. A reduced cardiac output secondary to reduction in venous return or drug-induced myocardial depression may reduce mixed-venous O₂ tension. However, Joris et al. [118], in a study of 20 patients free of cardiac disease and undergoing laparoscopic cholecystectomy, noted no significant increased intrapulmonary shunt, despite reduction in cardiac output and oxygen delivery.

The potential complication of pneumothorax following pneumoperitoneum has been discussed previously. Regurgitation and aspiration of gastric contents are potential complications of laparoscopic surgery. Duffy [119] reported gastric regurgitation in two of 93 fasting patients undergoing elective gynecologic laparoscopic procedures. Similarly, during laparoscopic cholecystectomy, there are several factors that increase IAP and that predispose to regurgitation, including the initial steep head-down tilt, insufflation of intraperitoneal gas and mechanical pressure exerted on the abdomen by the surgical team.

**Exogenous CO₂**

Historically, a number of gases have been used to facilitate laparoscopic surgery. Peritoneal gas insufflation is essential to enable exposure, visualization and manipulation of intra-abdominal contents. The ideal insufflation gas would be colorless, physiologically inert, in explosive in the presence of electrocautery and laser coagulation and capable of pulmonary excretion. Although nitrous oxide (N₂O) and room air have been used for diagnostic gynecologic procedures, they are unsuitable (i.e., flammable) when electrocautery is required. For these reasons, and because of its ready availability, low cost and proven efficacy, CO₂ has evolved as the insufflation gas of choice for laparoscopic surgery [107].

**Uptake and transport of CO₂:** A highly diffusible gas, CO₂ is absorbed across the peritoneal surface and is ultimately carried by the systemic and portal venous systems to the right heart and pulmonary circulation. According to Henry’s law of solubility, CO₂ concentration in solution (i.e., in plasma) will equal CO₂ partial pressure times its solubility coefficient [120]. Once in the blood, most of CO₂ diffuses into the erythrocytes, where hydration to carbonic acid occurs rapidly; the subsequent ionization is promoted by the buffering capacity of hemoglobin for the hydrogen ion. Considerable quantities of bicarbonate ion are, thus, formed and diffuse into the plasma in exchange for chloride ion. Lesser quantities of CO₂ are transported by hemoglobin as carbamino compounds. The ability of the body to store CO₂ varies with its metabolic production and exogenous CO₂ load, mixed venous CO₂ tension (Pv CO₂), cardiac output (Q), alveolar ventilation (VA) and the respiratory gas exchange quotient.

**Interactions of CO₂ and volatile anesthetic agents:** The interactions between exogenously administered CO₂, volatile anesthetics and ventilatory techniques have been the subject of extensive clinical investigations in the past two decades. Early reports of anesthesia for gynecologic laparoscopy using halothane emphasized the hazards of hypercarbia if patients were allowed to breathe spontaneously [7-8]. Several factors may contribute to the hypercarbia reported with halothane anesthesia and spontaneous ventilation: respiratory center depression by premedicant and anesthetic drugs; absorption of CO₂ from the peritoneal cavity; and impairment of ventilation by mechanical factors such as abdominal distension and the use of a steep Trendelenburg position. Hodgson et al. [121] emphasized the importance of keeping the intra-abdominal pressure less than 25 mm Hg in spontaneously ventilating patients, thus avoiding any unnecessary restriction of diaphragmatic movement.

Desmond and Gordon [115] reported increased PaCO₂ and the occurrence of arrhythmias in 10 spontaneously breathing patients anesthetized with halothane, and advocated controlled ventilation. Lewis et al. [122] observed that the PaCO₂ may be highest after the completion of the surgical procedure, once the intra-abdominal pressure has been
released, and suggested that patients may be at most risk of cardiac arrhythmias after completion of the procedure, independent of the technique of ventilation used. Scott [123] reported arrhythmias in up to 27 percent of patients undergoing spontaneous ventilation during laparoscopy. If N\textsubscript{2}O replaced CO\textsubscript{2} as the insufflation gas, the incidence of arrhythmias decreased to five percent, despite the use of halothane during spontaneous ventilation [124]. However, CO\textsubscript{2} remains the preferred gas, despite the increased postoperative discomfort associated with its use. Its greater solubility will minimize complications should inadvertent vascular injury occur [125]. The incidence of arrhythmias during laparoscopic cholecystectomy procedures in patients undergoing general anesthesia and spontaneous ventilation with other inhalational agents (e.g., enflurane, isoflurane or desflurane) remains to be reported.

The cardiopulmonary responses to CO\textsubscript{2} insufflation were prospectively evaluated by Liu et al. [107] in a study of 16 otherwise healthy patients undergoing laparoscopic cholecystectomy under general anesthesia with muscle relaxation. EtCO\textsubscript{2} and PaCO\textsubscript{2} increased from 31.4 ± 0.7 mm Hg to 42.1 ± 1.6 mm Hg, and from 33.3 ± 0.7 mm Hg to 43.7 ± 1.2 mm Hg, respectively, during the course of the procedure. Also, pH\textsubscript{a} decreased from 7.43 ± 0.01 to 7.34 ± 0.01, while bicarbonate concentration remained constant. Mean blood pressure increased from a baseline of 78 ± 2 mm Hg to 98 ± 2 mm Hg. This increase was coincidental with the maximal PaCO\textsubscript{2}. Similarly, Wittgen et al. [75] reported significant increases in PaCO\textsubscript{2} and decreases in pH\textsubscript{a} during CO\textsubscript{2} insufflation in a group of ten patients with previously documented cardiac and respiratory disease when compared with patients without underlying disease.

**Hemodynamic effects of exogenous CO\textsubscript{2}:** The hemodynamic consequences of intraoperative hypercarbia were addressed by Rasmussen et al. [111] in a study of 12 patients with ischemic heart disease in whom PaCO\textsubscript{2} levels reached 55 to 65 mm Hg. Significant increases in systolic blood pressure, heart rate and cardiac output were reported, while shortening of the pre-ejection period (PEP), left ventricular ejection time (LVET), and the decrease in PEP/LVET ratio suggested increased mechanical cardiac activity. It was suggested that hypercarbia caused sympathetic nervous system stimulation as demonstrated by the two to three-fold increase in plasma catecholamine concentrations.

A number of case reports have described acute hypotension, hypoxemia and cardiovascular collapse associated with laparoscopy [7, 126, 127]. Postulated causes included: a) hypercarbia, due to hypoventilation or absorption of CO\textsubscript{2} from the peritoneal surface, which may induce dysrhythmias, especially if the myocardium is sensitized by volatile anesthetic agents; b) reflex increase of vagal tone due to excessive stretching of the peritoneum; c) compression of the inferior vena cava, leading to decreased cardiac output; d) hemorrhage; and e) venous gas embolism. A number of case reports have described the clinical conditions associated with venous CO\textsubscript{2} embolism during laparoscopy [128, 129]. Venous CO\textsubscript{2} embolism in these cases was associated with profound hypotension, cyanosis and astyole after creation of pneumoperitoneum. The authors suggested that CO\textsubscript{2} could enter a tributary of the portal system during attempts at establishing the pneumoperitoneum.

**Reverse Trendelenburg position**

Laparoscopic cholecystectomy and upper abdominal surgical procedures are unique in that a change in body position from Trendelenburg when establishing pneumoperitoneum, to reverse Trendelenburg during dissection of the gall bladder and other structures, is necessary to avoid inadvertent bowel injury and to provide optimum exposure. Additional changes in position take place when the patient is placed supine at the time of intra-operative cholangiogram. The change in position to reverse Trendelenburg should be accompanied by respiratory advantages and cardiovascular disadvantages [93]. Venous
return, as determined by transesophageal echocardiographic assessment of left ventricular end-diastolic area, decreased following this position change [105]. The limited data available suggest that, in otherwise healthy patients, the cardiac output reductions associated with this intervention are insignificant [107]. However, these changes may not be so benign in patients with preexisting cardiorespiratory disease [106]. To date, there are no data regarding the effects of reverse Trendelenburg or of pneumoperitoneum on cerebral and coronary perfusion.

**SUGGESTIONS FOR ANESTHETIC MANAGEMENT**

*Anesthetic technique*

The choice of anesthetic technique for upper abdominal laparoscopic surgery is mostly limited to general anesthesia because of patient discomfort associated with creation of pneumoperitoneum and the extent of position changes associated with the procedure [129]. Controlled ventilation is recommended as several factors may induce hypercarbia, including depression of ventilation by anesthetic agents, absorption of CO₂ from the peritoneal cavity and mechanical impairment of ventilation by the pneumoperitoneum and the initial steep Trendelenburg position [87]. There have been, however, the occasional practitioners who lament the lack of clinical freedom implied in this recommendation and who claim, on the basis of their clinical experience that tracheal intubation is indicated if the surgeon is inexperienced, the duration of surgery unpredictable, an airway problem is present, if excess Trendelenburg tilt or CO₂ volume is required and for obese patients and those with preexisting cardiopulmonary disease [130].

High intra-abdominal pressures during laparoscopic cholecystectomy may increase the risk of passive regurgitation of gastric contents [117]. Outpatients presenting for laparoscopic cholecystectomy may have higher volumes of gastric contents at lower pH, increasing the potential risk of acid aspiration [131]. Cuffed endotracheal tube placement will minimize the risk of acid aspiration should reflux occur. Following induction of anesthesia, a urinary bladder catheter and nasogastric tube are placed. Bladder catheterization is undertaken to decompress the bladder and, thus, avoid trauma to intra-abdominal contents at the time of trocar insertion. Intraoperative gastric decompression may reduce the risk of visceral puncture at the time of creation of pneumoperitoneum, improve laparoscopic visualization and may facilitate retraction of the right upper quadrant structures [87].

*Local anesthesia:* Local anesthesia, in combination with 2 g/kg fentanyl, has been used for ambulatory laparoscopic gynecologic procedures [129]. Although a combination of abdominal and tubal insufflation with local anesthetic, paracervical block and 100 g fentanyl was advocated by Penfield as a suitable technique for ambulatory laparoscopic tubal ligation [132], there have been no reports on the use of local anesthesia for laparoscopic cholecystectomy. A technique of local anesthetic infiltration supplemented, if necessary, with intravenous sedation was described for bedside mini-laparoscopy procedures to evaluate patients who sustained blunt abdominal trauma [57].

*Regional anesthesia:* The effect of epidural anesthesia on control of ventilation has been investigated in healthy unpremedicated subjects [133]. The administration of 5 mg/kg lidocaine significantly increased the slope of the ventilatory response to CO₂, as the systemic effects of lidocaine may have a stimulating effect on ventilatory control mechanisms. High cervical levels of sympathetic denervation induced by epidural block with lidocaine did not impair circulatory and ventilatory responses to CO₂ in awake healthy humans [134]. In seven healthy female patients undergoing epidural anesthesia for laparoscopic tubal ligation, no significant changes in ventilatory variables were observed
while in the Trendelenburg position [135]. In contrast, CO₂ insufflation significantly increased minute ventilation (from 9.1 ± 1.0 L/min. to 11.8 ± 2.6 L/min.) and respiratory rate (from 16.9 ± 1.9 breaths/min. to 23.1 ± 3.3 breaths/min.), whereas PaCO₂ remained constant.

Local or regional anesthetic techniques, with the exception of correspondence concerning continuous epidural in patients with cystic fibrosis [136], have not been advocated for laparoscopic cholecystectomy or other upper abdominal surgical procedures. In this case, however, the author did not specify the local anesthetic volume and concentration used, the level of sensory block obtained and the effects of the sympathetic block and 30° to 40° sitting position on cardiac and respiratory function. The high level of sympathetic denervation required, the frequent need for change of patient position, and the mandatory pneumoperitoneum, may be associated with adverse ventilatory and circulatory responses in older or sicker patients undergoing laparoscopic cholecystectomy.

Furthermore, conversion to general anesthesia would be required if surgical conditions necessitated a change from laparoscopic to open cholecystectomy. Similarly, general anesthesia was the technique chosen for patients undergoing laparoscopic assisted colectomy [43, 44] and appendectomy [41].

**Anesthetic agents**

*Premedication and intraoperative agents:* Limited data are available concerning the, impact of anesthetic management on postoperative outcome following laparoscopic cholecystectomy. Staunton [87] reported an initial 42 percent incidence of nausea and vomiting in the postoperative period. A change in anesthetic technique, including the addition of an anti-emetic and substitution of intramuscular diclofenac for intravenous opioids, was associated with a reduction of these postoperative complications. Similarly, Parris and Lee [137] claimed that administration of the non-steroidal anti-inflammatory agent ketorolac tromethamine (60 mg IM following induction), intraoperative metoclopramide (10 to 20 mg IV) and prophylactic intravenous droperidol (0.625 mg IV before the end of surgery) essentially eliminated postoperative nausea. In prospective controlled studies, a number of investigators have reported impressive reductions in the incidence of postoperative nausea and vomiting in patients given intramuscular ketorolac 30 minutes before the end of surgery [138, 139]. Other investigators, however, have noted an opioid-sparing effect of ketorolac, which was associated with only minor differences in postoperative pulmonary function and no reduction in postoperative emesis, compared with placebo control [140]. The possibility of postoperative bleeding following the use of non-steroidal anti-inflammatory agents in patients who are discharged from the hospital relatively soon postoperatively needs to be evaluated further.

*Perioperative narcotic administration:* Intraoperative cholangiography may be crucial for the diagnosis of unsuspected common bile duct stones during laparoscopic cholecystectomy. Cholinergic agents or narcotics used before surgery for pre-anesthetic medication and during surgery as part of an intravenous-based anesthetic technique, have been reported to cause spasm of the choledochoduodenal sphincter (sphincter of Oddi) [141]. Spasm of the sphincter may create cholangiographic findings indistinguishable from those produced by a stone impacted in the common bile duct, causing unnecessary conversion to open cholecystectomy for exploration of the common bile duct. However, narcotic-induced spasm of the sphincter of Oddi may be antagonized by several drugs including naloxone [142], glucagon [143] and nalbuphine [144].

Fentanyl, a potent narcotic analgesic noted for its rapid onset of action, relative cardiovascular stability and negligible histamine release [145], is widely used in balanced anesthetic techniques. There are, however, conflicting reports on its effects on intrabiliary pressure (IBP). The potential difficulties associated with fentanyl supplemented anesthesia...
during laparoscopic cholecystectomy, however, seem overstated. Jones et al. [143] prospectively assessed the incidence of choledochoduodenal sphincter spasm during biliary tract surgery in 100 patients who received fentanyl in doses up to 10 g/kg as part of a balanced anesthetic technique. The incidence of failure of passage of the contrast material into the duodenum was three percent, but the spasm was reversed by the administration of 2 mg of glucagon in all patients. The advent of parenteral perioperative non-steroidal anti-inflammatory drugs and the tendency for less postoperative pain associated with the laparoscopic approach may obviate the need for perioperative narcotic administration.

Use of nitrous oxide: The use of N₂O during laparoscopic surgery is controversial because of concerns regarding its ability to produce bowel distension during surgery and to increase postoperative nausea. N₂O is about 30 times more soluble than N₂. Thus, a closed air-containing space may accumulate N₂O more rapidly than it can eliminate N₂. Eger and Saidman [146] observed an increase of more than 200 percent in intestinal lumen size after four hours of N₂O breathing. Lonie and Harper [147] reported a reduction in postoperative vomiting from 49 percent to 17 percent when N₂O was omitted in a prospective randomized study of 87 patients undergoing gynecologic laparoscopic procedures. Scheinin et al. [148] reported significantly less intraoperative bowel distension, earlier return of postoperative bowel function and shorter hospitalization in a group of patients randomized to receive either air or N₂O during elective colonic surgery.

In contrast, in an extensive randomized and blinded study involving 780 patients, Muir et al. [149] found no association between the use of N₂O and the subsequent development of postoperative nausea and vomiting. Interestingly, female gender, younger age, and a previous history of postoperative nausea and vomiting were found to be factors associated with increased incidence of postoperative nausea and vomiting. The safety and efficacy of N₂O specifically during laparoscopic cholecystectomy were investigated by Taylor et al. [150]. There were no significant differences between the groups receiving air and N₂O with respect to operating conditions or bowel distension. More importantly, there were no time-related changes in either variable during the course of surgery. Finally, the incidence of postoperative nausea and vomiting was similar in both treatment groups.

In summary, there is no conclusive evidence that demonstrates a clinically significant effect of N₂O on surgical conditions during laparoscopic cholecystectomy or on the incidence of postoperative emesis. With the caveats described above, N₂O, therefore, may still be a useful adjuvant during general anesthesia for this procedure.

Monitoring

In addition to placement of routine intraoperative monitors, a urinary bladder catheter and nasogastric tubes are introduced to decompress the viscera and, thus, avoid injury to intra-abdominal contents during trocar insertion. The most controversial issue regarding the appropriate monitoring of patients during laparoscopy is whether radial arterial cannulation should be undertaken to assess the effectiveness of oxygenation and ventilation after pneumoperitoneum creation. EtCO₂ is most commonly used as a non-invasive substitute for PaCO₂ in evaluating the adequacy of ventilation during laparoscopic cholecystectomy. However, EtCO₂ may differ considerably from PaCO₂ because of ventilation-perfusion (V/Q) mismatching, and erroneous clinical decisions may be reached if the two values are assumed to be equal, to change proportionally, or even to change in the same direction [151]. In a study of healthy, mechanically ventilated patients undergoing laparoscopic cholecystectomy, equal and proportional increases in EtCO₂ and PaCO₂ were observed following CO₂ insufflation [107]. McKinstry et al. [152] similarly commented that, in their series of relatively healthy patients, end-tidal CO₂ accurately predicted changes in PaCO₂. In this patient population, EtCO₂ monitoring should suffice.
In contrast, patients with preoperative cardiopulmonary disease demonstrated significant increases in PaCO₂ and decreases in pH after CO₂ insufflation, which were not reflected by comparable increases in EtCO₂ [75]. The difference between PaCO₂ and EtCO₂ (P[a-Et]CO₂) will increase if there is a greater contribution of ventilation from high V/Q regions. Therefore, radial artery cannulation for continuous blood pressure recording and frequent arterial blood gas analysis should be considered in patients with preoperative cardiopulmonary disease and in situations where intraoperative hypoxemia, high airway pressures or elevated EtCO₂ are encountered.

SUMMARY

Laparoscopic cholecystectomy is a relatively new surgical procedure enjoying ever increasing popularity and presenting new anesthetic challenges. The advantages of shorter hospital stay and more rapid return to normal activities are combined with less pain associated with the small limited incisions and less postoperative ileus compared with the traditional open cholecystectomy. The efficacy of laparoscopic appendectomy and hemicolecction have been recently evaluated. However, there have been no prospective randomized studies to date comparing laparoscopic with traditional laparotomy techniques. The physiological effects of prolonged pneumoperitoneum and the longer duration of surgery with the laparoscopic techniques are of concern. The application of laparoscopic inguinal hernia repair may be limited because, unlike traditional surgical repair, general anesthesia is required and concerns have been expressed about the duration of surgery and the possibility of hernia recurrence. Notwithstanding case reports and series describing successful diaphragmatic and hiatus hernia repair using a laparoscopic surgical technique, the frequently encountered complications of cervical surgical emphysema, pneumothorax and pneumomediastinum, attributed to passage of insufflating gas through weak points or defects in the diaphragm, must be of major concern. Anesthesiologists must maintain a high index of suspicion for these potential complication and must undertake appropriate monitoring. If there is clinical evidence of a tension pneumothorax, immediate chest tube decompression is indicated.

Intraoperative complications of laparoscopic surgery are mostly due to traumatic injuries sustained during blind trocar insertion and physiological changes associated with patient positioning and pneumoperitoneum creation. The choice of anesthetic technique for upper abdominal laparoscopic procedures is mostly frequently limited to general anesthesia. Controlled ventilation avoids hypercarbia, and an anesthetic technique incorporating antiemetics and non-steroidal anti-inflammatory agents has reduced postoperative nausea and vomiting following laparoscopic cholecystectomy. The use of nitrous oxide during laparoscopic procedures remains controversial.

Laparoscopic cholecystectomy is a major advance in the management of patients with symptomatic gallbladder disease. However, in the present era of cost containment, older and sicker patients may present for this procedure on the day of surgery without adequate preoperative evaluation. Anesthesiologists should, thus, be prepared to recommend conversion to an open procedure if hemodynamic, oxygenation or ventilation difficulties arise during the procedure.

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