Massive Subcutaneous Emphysema and Hypercarbia: Complications of Carbon Dioxide Absorption during Extraperitoneal and Intraperitoneal Laparoscopic Surgery—Case Studies

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While the laparoscopic approach to surgery is not new, its application has expanded tremendously within the past decade. Initially used as early as 1937 for gynecological procedures, it now is also a preferred method of approach in many general, urologic, and thoracic procedures. Examples of these procedures include tubal ligation, chromopertubation study, cholecystectomy, esophageal fundoplication, splenectomy, pelviscopy, and diagnostic thorascopy. In this article, the case studies involve the general surgery procedures of laparoscopic total extraperitoneal (TEP) inguinal herniorrhaphy and laparoscopic colectomy.

In the TEP approach for herniorrhaphy, a small incision is made in the midline near the umbilicus. An extraperitoneal space is created using blunt dissection or balloon inflation to expand the space. Laparoscopic instruments then are inserted into the abdominal wall through infraumbilical and suprapubic incisions. This extraperitoneal space is expanded further with carbon dioxide (CO2) insufflation. Once the hernia is dissected, a polypropylene mesh graft is inserted and then secured by mechanical means (eg, staples, sutures, or adhesives) or by allowing the patient’s own anatomy, postexsufflation, to contract, holding the mesh in place.

In a totally laparoscopic approach to colectomy, the initial incision is made at the umbilicus to allow the intraperitoneal insertion of the laparoscope and for the purpose of CO2 insufflation. Once the pneumoperitoneum is established, 3 or more lower abdominal incisions are made for additional port sites. The patient usually is placed in a lithotomy position with the arms tucked to maximize the surgeon's access to the abdomen and perineum. The specimen then is dissected and removed through the anus or through a colpotomy. The operation is completed with an end-to-end anastomosis, which can be accomplished either intracorporeally or extracorporeally.

We present 2 case studies that describe the circumstances contributing to a complication of laparoscopic surgery using CO2 as the insufflation gas: subcutaneous emphysema. Subcutaneous emphysema is defined as the presence of gas (CO2) within the tissue beneath the skin. It is identified by visualizing a smooth bulging of the skin and by palpation that produces an unusual crackling sensation as the gas is pushed through the tissue. More specifically, reference is made to a 4-point scale comparing varying degrees of subcutaneous emphysema:

- 0 = no subcutaneous emphysema
- 1 = mild emphysema with crepitus at trocar insertion sites or in the groin
- 2 = marked emphysema with crepitus extending to the abdomen and thighs
- 3 = massive emphysema extending to the chest or neck and face

Massive subcutaneous emphysema developed in both patients in the case studies described herein.
Case reports

Case 1 involved a 25-year-old, 88-kg man, ASA physical status II, who was scheduled for a laparoscopic TEP herniorrhaphy. The review of systems revealed a history of tobacco use and gastroesophageal reflux. The surgical history included strabismus repair and tonsillectomy with adenoidectomy as a child. The patient denied anesthetic complications with the previous surgical procedures and denied a family history of anesthetic complications. Ranitidine was the only prescribed medication.

In the preoperative area, the patient received midazolam, 3 mg intravenously, for its anxiolytic effects. Sodium citrate, 30 mL by mouth, also was administered along with 10 mg of metoclopramide and 50 mg of ranitidine intravenously because of the history of reflux. Once in the operating room, standard monitors (5-lead cardiac monitor, blood pressure, pulse oximeter, oxygen analyzer, respiratory gas analyzer, and end-tidal CO2 [ETCO2] analyzer) were placed, and the patient was preoxygenated. General anesthesia was induced with 150 µg of fentanyl, 2 mg/kg of propofol, and 1 mg/kg of succinylcholine intravenously. The patient was atraumatically intubated on the first attempt. Anesthesia was maintained with desflurane, air, and oxygen. Additional boluses of fentanyl were administered according to hemodynamic response. Mivacurium, used to facilitate operating conditions, was titrated by using the train-of-four with a peripheral nerve stimulator.

Initially the trocars were placed approximately 12 minutes after induction of anesthesia. The ventilator was set to deliver a tidal volume (TV) of 700 mL and a rate of 8 breaths per minute. The initial peak inspiratory pressure was 16 cm of water. The initial ETCO2 was 40 mm Hg. After approximately 20 minutes of CO2 insufflation with an intracavitary pressure ranging from 14 to 18 cm of water, the patient's ETCO2 began to climb and reached a peak of 65 mm Hg. The peak inspiratory pressure increased to 30 cm of water. The ventilator rate was increased steadily to 15 breaths per minute in response to the increasing ETCO2. Maximum ventilator settings eventually were as follows: TV, 900 mL; respiratory rate, 15; and peak inspiratory pressure, 35 cm of water, producing a minute ventilation of 13.5 L/min (normal is 5 L/min). The fraction of inspired oxygen (FiO2) was increased to 1.0 from 0.5. Ventilator changes reduced the ETCO2 to a minimum of 50 mm Hg during the insufflation period.

The surgeon was notified of the increase in the ETCO2 despite increases in both respiratory rate and TV. Potential causes for a rapid rise in ETCO2 were considered, including a hypermetabolic state (as with malignant hyperthermia), shivering, bronchospasm, and pneumothorax. On examination, there were no other signs to support the presence of any of these other problems. However, the patient was noted to have subcutaneous emphysema in the inguinal area and scrotum. Additional palpation revealed skin crepitus extending from the operative site into the trunk, neck, and face. Arterial blood gas measurements were obtained in the operating room. The results were as follows: pH, 7.29; PCO2, 60 mm Hg; Po2, 180 mm Hg; bicarbonate, 28 mEq/L (28 mmol/L); base excess, 2; and oxygen saturation, 100% on an FiO2 of 1.0. All were consistent with respiratory acidosis.

The operation ended within 15 minutes of reaching the peak ETCO2. Once the trocars were removed and the insufflation of CO2 ceased, the patient's condition was reevaluated. He remained intubated, and the anesthetic was continued along with controlled ventilation until the ETCO2 was less than 45 mm Hg. The muscle relaxant was allowed to metabolize spontaneously. The patient was extubated in the operating room 15 minutes after the completion of surgery and had a spontaneous respiratory rate of 18 breaths per minute, a TV of 450 mL per breath, a full train-of-four with sustained tetanus on the peripheral nerve stimulator, and an oxygen saturation of 95%. The patient then was transferred to the postanesthesia care unit where he remained for 60 minutes until transfer, in stable condition, to the same-day surgical unit. The patient was discharged home the same day. When phoned the next day as part of a routine postoperative follow-up, the patient noted that the crepitus had resolved substantially.

Case 2 involved a 44-year-old, 65-kg woman, ASA physical status II, with a history of obstipation (chronic and severe constipation) and laxative dependence. The patient was scheduled to undergo a laparoscopic subtotal colectomy. The review of systems was remarkable only for a 30 pack-year history of tobacco use. The patient's surgical history was significant for multiple abdominal procedures, including hysterectomy, cholecystectomy, appendectomy, bilateral tubal ligation, and 2 cesarean sections. She had received both regional and general anesthetics in the past and denied having experienced any anesthesia-related complications. Conjugated estrogen (Premarin) was the only prescribed medication the patient was taking. She denied routinely using over-the-counter medications and herbal remedies.

In the preoperative area, monitors were placed on the patient. The patient then was given midazolam, 2 mg intravenously, for the anxiolytic effect and fentanyl, 50 µg intravenously, in preparation for place.
The patient's ETCO₂ began to climb, from 32 mm Hg to 52 mm Hg, and then dosed further using 50 µg of fentanyl and 7 mL of 2% lidocaine with epinephrine 1:200,000. The patient then was transferred to the operating room. Standard monitors were placed, and an intravenous induction was accomplished after preoxygenation using propofol (2 mg/kg), rocuronium (0.5 mg/kg), and an additional dose of fentanyl (100 µg).

Following an atraumatic intubation, an orogastric tube and esophageal stethoscope were placed. Anesthesia was maintained using sevoflurane, 50% oxygen, and air, as well as titrated doses of rocuronium to maintain a 2/4 train-of-four. Bupivacaine, 0.25% (5 mL), and fentanyl (50 µg) were administered via the epidural at 60- to 90-minute intervals. The patient was placed in the lithotomy position with arms positioned at approximately 80° angles to her sides. Throughout the surgery, orientation of the operating table varied: Trendelenburg, reverse Trendelenburg, flat, and tilting to the right or left at the surgeon's request.

Within 15 minutes of the start of surgery, the patient's ETCO₂ began to climb, from 32 mm Hg to 52 mm Hg at case end when the patient was breathing spontaneously. The TV was set between 600 and 700 mL per breath. Peak inspiratory pressure ranged between 17 and 32 cm of water. The ventilatory rate was progressively increased in response to rising ETCO₂ readings, starting at 10 breaths per minute and peaking at 20 breaths per minute. Breath sounds remained clear. The intracavitary pressure with insufflation never exceeded 18 mm Hg (average pressure, 14-17 mm Hg).

A near-total colectomy was required, and the specimen was removed through the anus. An end-to-end anastomosis was accomplished through the rectum. The case otherwise was done entirely under laparoscopy. Five trocar insertion sites were used.

Facial swelling was noted late in the case but initially was attributed to frequent and prolonged Trendelenburg positioning. However, with removal of the surgical drapes at case end, a more extensive evaluation revealed generalized swelling over the patient's chest, neck, and face (including the eyelids). A definite crepitus was noted on palpation over the same areas. The surgeon was made aware of these findings. Muscle relaxation had been reversed, and the patient was breathing spontaneously. The patient's ETCO₂ was 50 mm Hg, her respiratory rate was 15 breaths per minute, and the pulse oximetry reading was 100% with an Fio₂ of 1.0. To determine the extent, if any, of pharyngeal swelling, the patient's oropharynx was suctioned and the endotracheal tube cuff was deflated. A leak was clearly audible around the cuff. The decision to extubate was made, the cuff was re-inflated, and the patient was allowed to emerge from the anesthetic. Once she met extubation requirements and her oropharynx again was suctioned, a leak again was obvious with cuff deflation. She was extubated and exhibited no evidence of airway compromise.

The patient remained in stable condition in the postanesthesia care unit. The presence of subcutaneous emphysema was explained to the patient and her spouse. Arterial blood gas measurements were not obtained because it was presumed the subcutaneous emphysema was secondary to an iatrogenic absorption of CO₂.

Discussion

There are a number of advantages and disadvantages to laparoscopic surgery. Compared with the same procedures done using an open approach, patients who undergo laparoscopic procedures experience less pain. The hospital stay and overall recovery times are significantly shorter, believed to be the result of a lack of muscle splinting. Without muscle splinting there is less need for analgesia and its associated complications. All of this contributes to lower overall costs.

However, depending on the surgeon's experience, a longer operative time compared with an open approach to the same surgery may be required. This can add to the intraoperative cost and to the need for special laparoscopic equipment and surgical assistance. Other disadvantages of laparoscopy include the remote (ie, < 0.8%) possibilities of hemorrhage from a trocar site or major vascular damage, perforating visceral injuries, and cardiac arrest from gas embolism.

The creation of a pneumoperitoneum can place the patient at risk. While it is possible to enlarge the intraperitoneal space by applying external traction to the abdominal wall, thereby elevating it, distention by way of gas insufflation has proven more advantageous. Several gases have been used for insufflation (Table). But CO₂ has proven to be the safest of these gases because it does not support combustion and is more soluble in blood. However, the pneumoperitoneum (or pneumoextraperitoneum as in the case of the TEP herniorrhapsy) created by the insufflation of CO₂ can create multiple complications. Some reported complications include dysrhythmias, hypercapnia, atelectasis, pneumothorax, pneumomediastinum, and subcutaneous emphysema.
The anatomic and physiologic changes that occur as a result of pneumoperitoneum with CO2 include the following: reduced venous return from the lower extremities, reduced cardiac output and index, cardiac axis shift, marked reduction in functional residual capacity, increased peak airway pressures, ventilation perfusion mismatch, and increased alveolar/arterial O2 gradient.5,6

- Carbon dioxide absorption and elimination. At rest, the body cells consume approximately 200 mL/min of oxygen and produce the same amount of CO2. As CO2 leaves the cells, it is transported by the tissue capillaries and then the venous blood into the pulmonary capillaries where it must cross the alveolar membrane to be exhaled into the atmosphere.11 Excess CO2 introduced while creating a pneumoperitoneum or pneumoextraperitoneum must be absorbed from the tissue, transported in the blood, cross the alveolar membrane, and be exhaled into the atmosphere in a manner exactly mirroring the body’s normal physiologic process. Without an increase in the minute ventilation, hypercapnia will ensue.

Maintaining eucapnia may require an increase in the minute ventilation by 20% to 30%. Minute ventilation (MV) is defined as the TV multiplied by the respiratory rate.11 An average adult (70 kg) has a resting TV of 5 mL/kg and a respiratory rate of 15 breaths per minute. This gives an average MV of 5 L/min. It is common to increase the TV to 10 mL/kg when a patient is ventilated mechanically and to adjust the respiratory rate to maintain eucapnia. However, for the patient in case 1, who underwent an extraperitoneal approach, the changes in respiratory rate and TV did not provide a sufficient MV to compensate for the CO2 absorbed during the procedure.

The literature reveals multiple case reports of CO2 diffusing outside the intraperitoneal and extraperitoneal cavities causing pneumothorax, pneumomediastinum, pharyngeal emphysema, and CO2 embolism.4,8,9,12 Subcutaneous emphysema also is listed frequently as a possible complication of laparoscopy. Sumpf et al4 described the results of a double blind trial in which patients were divided into 2 groups based on different endoscopic herniorrhaphy techniques. The authors studied the perioperative CO2 absorption and the ventilatory changes required to maintain eucapnia in 20 patients undergoing either transabdominal preperitoneal (TAPP) or TEP herniorrhaphy.

The authors found that CO2 absorption reached plateau value in the TAPP group but increased over time in the TEP group. The authors’ findings are significant. All patients in the TEP group had significant subcutaneous emphysema. One case resulted in delayed tracheal extubation. Seven of 10 patients in the TEP group required an MV in excess of 18 L/min. No patient in the TAPP group required more than 14 L/min. The authors concluded that CO2 absorption is consistently less with TAPP herniorrhaphy.

Another study compared ETCO2 tension and pulmonary CO2 (VECO2) elimination during CO2 insufflation in both intraperitoneal and extraperitoneal surgeries. Maintaining a constant TV (10 mL/kg) and respiratory rate (12/min), Mullet et al12 examined these parameters in 30 patients undergoing laparoscopy, 10 each having intraperitoneal general surgery, intraperitoneal gynecologic surgery, or extraperitoneal gynecologic surgery. The duration of CO2 insufflation was similar for the gynecologic surgeries and nearly 3 times as long for the general surgeries. Despite this difference, the time to return to preinsufflation values in the patients who had intraperitoneal CO2 was 10 minutes on average. However, patients who had extraperitoneal insufflation continued to have markedly elevated ETCO2 tension and VECO2 at least 45 minutes from cessation of insufflation.

The authors in the aforementioned studies theorized a potential reason for these disparities. Sumpf et al4 concluded that CO2 absorption might decrease once the pressure within the peritoneum reaches a set point due to a tamponade effect on capillary blood flow. Authors for both studies noted that as the extraperitoneal space is a potential space rather than actual space, no definite pressure set point or tamponadelike effect is achieved during CO2 insufflation. In contrast with the intraperitoneal space, the

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**Table. Gases used for insufflation during laparoscopy**

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<thead>
<tr>
<th>Gas</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Carbon dioxide</td>
<td>Noncombustible; rapid absorption</td>
<td>Hypercarbia; requires intermittent reinsufflation</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>Greater safety margin; less hypercapnia</td>
<td>Supports combustion</td>
</tr>
<tr>
<td>Helium</td>
<td>Inert; does not support combustion</td>
<td>Inert; emboli not rapidly absorbed; expensive</td>
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Adapted from Bready.5(p46)
extraperitoneal space can continue to expand by dissection with the insufflating gas and, therefore, can absorb the CO₂ without reaching a comparable steady state. During intraperitoneal surgery, the CO₂ elimination eventually reaches steady state after a set period of insufflation. In the study by Sumpf et al, the time to steady state was 20 minutes. And, in the study by Mullet et al, the time to steady state was 15 minutes. However, no steady state for CO₂ elimination was achieved during the course of insufflation during the extraperitoneal cases.

Both patients in the present case reports experienced massive subcutaneous emphysema. In addition, one patient also demonstrated marked hypercapnia during the CO₂ insufflation for which increasing his minute ventilation to 13.5 L/min proved insufficient. Fortunately for these otherwise healthy patients, these occurrences did not cause anesthetic complications. Murdock et al demonstrated that preexisting conditions, including cardiac disease, pulmonary disease, and hypertension, did not predispose the patient to the development of subcutaneous emphysema. However, the hypercapnia associated with subcutaneous emphysema will place the patient at risk for anesthetic complications.

For example, intraoperative cardiac dysrhythmias are associated with volatile anesthetics, hypoxemia, hypertension, tracheal intubation, cardiac disease, and hypercapnia. Hypercapnia contributes to the occurrence of dysrhythmias as a result of enhanced automaticity or an increase in the slope of phase 4 depolarization in the cardiac action potential. A PaCO₂ of 55 to 70 mm Hg can result in systolic hypertension, increased central venous pressure, tachycardia, and decreased peripheral vascular resistance.

If prolonged, hypercapnia will lead to respiratory acidosis. In the unanesthetized patient, compensation takes the form of an increased rate of ventilation, which is mediated by the medullary chemoreceptors, an increase in the plasma concentration of bicarbonate produced by hydration of CO₂, and renal reabsorption of bicarbonate into the arterial system. However, while the first 2 compensatory mechanisms start within seconds of an increase in the serum CO₂ level, the renal response requires 48 to 72 hours. The anesthetized and mechanically ventilated patient has been rendered incapable of the ventilatory response. And if there is not adequate compensation, the serum pH can fall below 7.0. In addition to cardiac dysrhythmias, significant depression of the central nervous system also may ensue.

At our institution, all laparoscopic surgeries are done under general anesthesia. The patient populations undergoing these laparoscopic procedures range from ASA physical status I through III. As such, it is not unusual to provide anesthesia to a patient with predisposing factors for complications secondary to hypercapnia.

So what implications does this have for our practice? By anticipating hypercapnia with laparoscopic surgeries using CO₂ insufflation, the anesthetist may make the required compensatory ventilator changes. As the ETCO₂ increases, other possible causes for this rise should be ruled out. A continued rise in ETCO₂ despite the increase in the MV needs to be discussed with the surgeon, temporarily ceasing insufflation until the patient's ETCO₂ returns to within normal limits.

If subcutaneous emphysema is discovered intraoperatively, these findings should be communicated to the surgeon and extension of the emphysema should be monitored. Possible postoperative problems include prolonged hypercapnia, pharyngeal swelling that may cause airway compromise, facial swelling that may temporarily impair vision, and pain management challenges. Additional postoperative tests include a chest radiograph to rule out pneumothorax and/or pneumomediastinum as well as arterial blood gases to evaluate the extent of the hypercapnia.

Conclusion
In light of the enormous push toward laparoscopic surgery as a means to significantly reduce the average length of hospitalization, patient recovery times, and cost, anesthesia providers must anticipate and prepare for the unique challenges presented with these techniques.

Massive subcutaneous emphysema developed in both patients in these case studies. Hypercapnia developed in both patients, hypercapnia for which changes in mechanical ventilation were implemented to maintain a normal ETCO₂. An MV approximately 2.5 times normal failed to maintain the ETCO₂ within a normal range for the patient undergoing an extraperitoneal approach. The patient also experienced prolonged hypercapnia into the postoperative period. However, the same intervention of increasing the MV proved successful in maintaining an acceptable ETCO₂ for the patient undergoing an intraperitoneal approach. We believe these findings support the hypothesis that the extraperitoneal space continues to expand, thereby providing more surface area for CO₂ absorption. As the CO₂ continues to dissect the extraperitoneal space, subcutaneous emphysema develops. Over time, massive subcutaneous emphysema can occur. During intraperitoneal CO₂ administration, a tamponade effect eventually maximizes the surface area for absorption. As intraperitoneal CO₂...
leaks into the extraperitoneal space from trocar sites, subcutaneous emphysema can occur.

The complication of subcutaneous emphysema occurred in these 2 patients as a result of CO2 leaking into the subcutaneous tissue during both extraperitoneal and intraperitoneal insufflation. Surgery was accomplished successfully, and both patients recovered from the massive subcutaneous emphysema during a period of 2 to 3 days.

REFERENCES

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