35. Pulmonary Implications of CO_2 Pneumoperitoneum in Minimally Invasive Surgery

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Laparoscopic methods are associated with intraoperative pulmonary alterations in all patients, even those who are young and healthy. Factors that affect pulmonary function during laparoscopic procedures include the pneumoperitoneum-related (secondary to increased pressure) elevation of the diaphragms, carbon dioxide-related physiologic changes, and the radical body positions that are usually required to facilitate performance of the procedures (Table 35.1). Obesity and certain other patient comorbidities may further affect pulmonary function. Finally, intraoperative complications of the procedures can produce abrupt, life-threatening changes in pulmonary function.

A. Effects of the Pneumoperitoneum

Creating a pneumoperitoneum increases the abdominal pressure that pushes the diaphragm cephalad and decreases the volume of the chest cavity. The functional residual volume is thereby diminished and the work of breathing is increased. Lung compliance is decreased. If the patient is under a general anesthetic with a fixed tidal volume, the peak inspiratory pressure will be increased. If the patient is ventilating spontaneously without neuromuscular blockade, the tidal volume will be decreased and atelectasis will generally occur. Pulmonary shunting then occurs and contributes to a decrease in arterial oxygenation.

The use of abdominal wall lifting devices to provide laparoscopic exposure avoids the pneumoperitoneum and CO_2-related deleterious pulmonary effects. The cardiopulmonary alterations are, therefore, minimal when the position is neutrally positioned. However, when the patient is placed in the Trendelenburg position, deleterious pulmonary function abnormalities are noted that are similar to those observed in similarly positioned CO_2 pneumoperitoneum patients. Largely because abdominal wall lifting methods provide inferior exposure, they have not gained widespread acceptance.

The anesthesiologist who is taking care of laparoscopic patients, especially those undergoing a CO_2 pneumoperitoneum, must be ready to increase the respiratory rate, which will increase the minute ventilation and, if need be, increase the oxygen concentration during the procedure. Appropriate intraoperative monitoring techniques are discussed in a later section.

Table 35.1. Effects of laparoscopy on pulmonary function.

Factor	Immediate result	Effect on pulmonary function
Pneumoperitoneum	↑ Abdominal volume ↑ Abdominal pressure (resulting in elevation of diaphragms)	↓ Lung volumes • Decreases the functional residual capacity • Decreases the tidal volume • Decreases the vital capacity ↓ Lung compliance ↑ Peak inspiratory pressure • Atelectasis → alveolar-arteriolar • O_2 mismatch → resulting in ↓PaO_2
CO_2 insufflation	Hypercarbia	Hyperventilation (in spontaneously breathing patient)
	Acidosis	Increased minute ventilation (in spontaneously breathing patient)

B. Physiologic Effects of CO2 Insufflation

Carbon dioxide is almost universally employed to create and maintain pneumoperitoneum during laparoscopic procedures. Although air, helium, nitrogen, oxygen, nitrous oxide and argon have been considered as gases for insufflation, CO_2, in the final analysis, has been found to be superior because it is extremely soluble, nonflammable, inert, and nonirritating. CO_2 is rapidly absorbed across the peritoneal membrane into the bloodstream and equilibrates quickly, with a diffusion coefficient 20 times that of oxygen or helium and 40 times that of nitrogen. Thus, the risk of gas embolism is far less with CO_2 than with the other gases mentioned. Most of the absorbed carbon dioxide is eventually eliminated by the lungs. The high solubility of CO_2 has several important negative ramifications.

The rapid equilibration of carbon dioxide results in significant hypercarbia and acidosis, which, in turn, may influence cardiac and pulmonary function. Aortic and carotid body chemoreceptors normally respond to hypercarbia by relaying afferent impulses to respiratory centers that result in hyperventilation and the increased elimination of CO_2 through the lungs. Because most laparoscopic procedures are performed with controlled ventilation under general anesthesia, the normal compensatory hyperventilation does not occur and hypercarbia persists unless the respiratory rate or tidal volume is increased by the anesthesiologist.

C. Effects of Patient Position

Patient positioning during surgery can also significantly affect pulmonary function. Due to a cephalad shift in the abdominal viscera and upward pressure on the diaphragm, the Trendelenburg position causes further decreases in lung volume, functional residual capacity, and pulmonary compliance beyond that seen with pneumoperitoneum alone. Overall, the Trendelenburg position further increases the work of breathing. The trachea also shifts in the cephalad direction with the patient in the head-down position so that the tip of an endotracheal tube that is secured at the mouth may advance into the right main-stem bronchus. The simultaneous increased intraabdominal pressure further exacerbates this shift in position of the tracheal bronchial tree. The reverse Trendelenburg position improves pulmonary mechanics by increasing lung volumes and lessening the work of breathing.

D. The Impact of Comorbid Conditions

In general, the mechanical work of breathing is increased and pulmonary compliance is decreased in obese patients. This is partly because obese patients at baseline have increased intraabdominal pressures. In this population, laparoscopic procedures done under a CO_2 pneumoperitoneum not surprisingly result in more dramatic pulmonary function alterations than are noted in the general population. Similarly, body position changes during surgery in this population are associated with more striking pulmonary function alterations. The Trendelenburg and even the supine position further impair pulmonary function whereas the reverse Trendelenburg position, which is commonly employed during upper abdominal procedures, lessens the deleterious pulmonary effects of both obesity and pneumoperitoneum.

Individuals with severe preexisting lung or heart disease are at the greatest risk for serious CO_2 pneumoperitoneum-related pulmonary function alterations. The pulmonary effects of pneumoperitoneum are often noted earlier and are more dramatic in this patient population. In this population, especially those with restrictive lung disease, it is also harder to correct these changes by increasing the minute ventilation or inspiratory pressures; therefore, conversion to open surgical methods is necessary more often than in the general population. As is the case for obese patients, the Trendelenburg position impact on pulmonary function is accentuated in patients with severe cardiopulmonary disease.

The principal effects of preexisting lung disease are to exacerbate the hypercarbia and acidosis associated with the CO_2 pneumoperitoneum. Although the increased intraabdominal pressure contributes to these alterations, it is probably the CO_2 gas itself that is the main cause of the dramatic hypercarbia and acidosis often noted in these patients. Chronic obstructive pulmonary disease (COPD) patients with chronic carbon dioxide retention, at baseline, have nearly or fully saturated their body's CO_2 storage sites, such as the bone and skeletal muscle, and have a limited ability to accommodate additional CO_2 during a laparoscopic procedure. These individuals often manifest an exaggerated hypercarbia when compared to patients with normal lung function and require more time to eliminate the CO_2 through their lungs after desufflation. As mentioned above, increasing the minute ventilation in patients with chronic pulmonary disease may not adequately compensate for the hypercarbia and acidosis; in these cases conversion to traditional open methods may be necessary (see Section F).

E. Effects of Anesthetic Method on Pulmonary Function

The anesthetic technique chosen for a given laparoscopic procedure has important ramifications in regard to intraoperative pulmonary function. Local anesthetics with sedation are satisfactory only for brief lower abdominal procedures in motivated healthy patients because insufflation of the abdominal cavity irritates the diaphragm and restricts the patient's voluntary inspiratory efforts. Similarly, the high level of spinal or epidural anesthetic required to achieve adequate abdominal wall muscle relaxation and eliminate diaphragmatic irritation prevents the patient from increasing spontaneous ventilation to the extent that CO_2 levels are maintained within normal limits. Therefore, a general anesthetic with endotracheal intubation and positive-pressure mechanical ventilation is necessary for most laparoscopic procedures. Endotracheal intubation decreases the risk of aspiration of gastric acid when regurgitation occurs as a result of insufflation-related elevated intraabdominal pressure. Controlled ventilation allows the respiratory rate and tidal volume to be adjusted in response to hypercarbia and changes in patient position. Peak inspiratory pressures can be increased as necessary to counteract the effects of pneumoperitoneum on lung volumes. Muscle paralysis minimizes the volume of insufflated gas and the peak insufflation pressure needed to provide adequate abdominal exposure. The lower the peak insufflation pressure, the smaller the lung volume alterations and the less extreme the hypercarbia.

Careful monitoring of the patient during CO_2 pneumoperitoneum provides the anesthesiologist with the information needed to make respiratory rate, volume, or pressure changes to adequately ventilate and oxygenate the patient. All patients undergoing general anesthesia routinely have the following functions monitored: arterial blood pressure, heart rate, body temperature, ECG, O_2 saturation, and end-tidal CO_2 levels. The latter measurement is critical for laparoscopic procedures because it gives the anesthesiologist moment-to-moment indirect data regarding the Pa CO_2. Arterial blood gases (ABGs) are the "gold standard" in regard to determining arterial oxygen and CO_2 levels as well as the blood pH during an operation; however, these tests are done sporadically during a case. End-tidal CO_2 monitors reveal the CO_2 concentration of the expired gas in a continuous fashion. It is important to note that there is always a gradient between the Pa CO_2 and the end-tidal CO_2; the latter is always lower than the former. The size of this gradient varies from patient to patient (as little as 5 mmHg to 20 mmHg or higher). Those with significant pulmonary disease manifest a larger gradient than patients with normal lungs. For the anesthesiologist to correctly extrapolate the $PaCO_2$ from the end-tidal CO_2, the size of the gradient needs to be determined at the start of the procedure via correlation of the end-tidal value and a blood gas-derived Pa CO_2. The arterial–end-tidal CO_2 gradient may be altered when lung perfusion suddenly changes and alters the volume of alveolar deadspace. Decreased lung perfusion will increase the alveolar deadspace, which, in turn, dilutes the CO_2 in the expired gas and hence results in a lower end-tidal CO_2 level. These changes may occur when the cardiac output suddenly decreases as a result of high inflation pressures, reverse Trendelenburg position, or gas embolism. Therefore, it is recommended that reassessment of the CO_2 gradient, via repeat ABGs, be carried out periodically during a long laparoscopic case, especially for patients with significant pulmonary disease.

In patients with pulmonary impairment, preoperative ABGs should be obtained as a baseline for comparison with intraoperative values. Formal pulmonary function tests are also useful preoperatively in this population. Evidence of decreased flow rates, limited vital capacity and inspiratory capacity, and decreased diffusion capacity correlate with intraoperative acidosis. If the forced expiratory volume (FEV) is significantly compromised (less than 70%) and diffusion capacity is less than 88% of predicted values, the patient is at increased risk of developing hypercarbia and acidosis. Patients with significantly compromised pulmonary function should have an arterial line placed before the start of the surgical procedure and, as mentioned above, have frequent blood gas analysis. The anesthesiologist needs to closely monitor these patients intraoperatively and to frequently update the surgeon as to the patient's end-tidal CO_2, the tidal volume, and minute ventilation, as well as the size of the CO_2 gradient.

F. Minimizing Insufflation Pressures and Pneumoperitoneum "Holiday"

The surgeon must strive to use as low an insufflation pressure as possible during all laparoscopic cases. Reducing the pressure limit from 15 to 12 or to 10 mmHg will decrease the mechanical pulmonary function and blood gas alterations. A sizable percentage of cases can be successfully completed using a reduced peak insufflation pressure. Another useful tool or strategy when attempting to complete a laparoscopic case in a patient who is retaining CO_2 despite all the usual maneuvers is to simply stop the dissection, fully desufflate the abdomen, and place the patient in reverse Trendelenburg for 5–10 minutes. This pneumoperitoneum "holiday" removes the iatrogenic source of the problem and permits the patient to lower their $PaCO_2$. Once the end-tidal CO_2 has fallen sufficiently, the pneumoperitoneum can be reestablished and the procedure recommenced.

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