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Subcutaneous Emphysema—Beyond the Pneumoperitoneum

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ABSTRACT

Background: Subcutaneous emphysema and gas extravasation outside of the peritoneal cavity during laparoscopy has consequences. Knowledge of the circumstances that increase the potential for subcutaneous emphysema is necessary for safe laparoscopy.

Methods: A literature review and a PubMed search are the basis for this review.

Conclusions: The known risk factors leading to subcutaneous emphysema during laparoscopy are multiple attempts at abdominal entry, improper cannula placement, loose fitting cannula/skin and fascial entry points, use of >5 cannulas, use of cannulas as fulcrums, torque of the laparoscope, increased intra-abdominal pressure, procedures lasting >3.5 hours, and attention to details. New additional risk factors acting as direct factors leading to subcutaneous emphysema risk and occurrence are total gas volume, gas flow rate, valveless trocar systems, and robotic fulcrum forces. Recognizing this spectrum of factors that leads to subcutaneous emphysema will yield greater patient safety during laparoscopic procedures.

Key Words: Subcutaneous emphysema, Carbon dioxide, Gas volume, Pneumoperitoneum, Laparoscopic safety.

INTRODUCTION

It is important to know where the gas travels during laparoscopic surgery. Placing trocars through the abdominal wall requires more than skill. A planned approach requires consideration of the patients' topography and habitus; knowledge of the surgical procedure; modifications based on specific circumstances peculiar to the patient, number, placement, angle, and trajectory of the trocars; understanding the instruments and devices being deployed and their intended uses, capabilities, and limitations; alternatives to routines, a "plan B"; an ability to assess and handle adversity and complications; and overcoming arrogance and overconfidence. The focus of this review is to consider the why, what, where, and who of gas intended to distend the peritoneal cavity extending beyond the intended site and to increase awareness of the conditions that effect extravasation of gas beyond the intra-abdominal cavity confines during laparoscopy.

Choices, Decisions, Consequences

The potential for subcutaneous emphysema starts with the physician's preparation, knowledge, and experience. A decision regarding the strategy of trocar placement appropriate for the planned procedure precedes an incision. The access incision is followed by a series of events affecting how and where the gas goes and its eventual clinical consequences. The incision(s) (number and size), trocar(s) (number and size), incision/size relationship to trocar size, trocar placement and angle (skin and fascia relationship), fulcrum effect, torque, gas pressure, flow rate and end-point pressure setting, gas volume used, and abdominal wall compliance all influence the appropriateness, completeness, and status of a pneumoperitoneum (**Table 1**).

Carbon dioxide (CO_2) is listed in the United States Pharmacopeia and is sold with the following labeling: "WARNING! Administration of Carbon Dioxide may be hazardous or contraindicated. For use only by or under the supervision of a licensed practitioner who is experienced in the use and administration of Carbon Dioxide and is familiar with the indications, effects, dosages, methods and frequency and duration of administration, and with the hazards, contraindications, and side effects and

Table 1.
Factors Leading to Subcutaneous Emphysema

Insufflator (high gas flow and high gas pressure setting)

Intra-abdominal pressure >15 mm Hg

Multiple attempts at the abdominal entry

Veress needle or cannula not placed in the peritoneal cavity

Skin/fascial fit/seal around the cannulas is not snug

Use of >5 cannulas

Laparoscope used as a lever

Cannula acting as a fulcrum

Long arm of the laparoscope is a force multiplier

Tissue integrity compromised by repetitive movements

Structural weakness caused by repetitive movements

Improper cannula placement, causing stressed angulation

Soft tissue dissection and fascial extension

Gas dissection leading to more dissection

Procedures lasting >3.5 hours

Positive end-tidal CO_2 >50 mm Hg

the precautions to be taken." The volume of gas consumed during laparoscopy is important missing data that must be charted along with pressure settings and flow rate. The length of time an operation takes is an important data point, as is the length of anesthesia administration and the type, strength, amount, and volume of drugs used for inhalation or other therapeutic reasons (eg, analgesia, cardiac or blood pressure), but it is not the same as the CO_2 gas volume used during laparoscopy.

Gas Volume and Flow Rate

Insufflator flow rate and pressure settings allow gas to be forced from a high-pressure gas system to a low-pressure container (insufflator to abdomen), expanding the cavity. If the entry site is appropriate in size (snug fit), there is no tear in the peritoneum other than trocar penetration, and the trocar extends beyond the peritoneum, gas dissection outside the peritoneal cavity is unlikely and gas is pumped into the intra-abdominal space until back-pressure resistance stops expansion at the predetermined pressure set point. Once a sufficient intra-abdominal space is secured for the surgical procedure, gas flow should be discontinued, even if it is below the pressure set point. Gas insufflation into the peritoneal cavity without increased distention increases intra-abdominal pressure (IAP) and does not increase operating space. Each increase in pressure in the abdomen (in mm Hg) is transmitted against the inner ab-

dominal wall and transmitted to tissues, resulting in decreased perfusion, hypoxia, increased gas absorption, and increased likelihood of tissue dissection and subcutaneous emphysema. The "safe" range of pneumoperitoneum IAP is 0 to 20 mm Hg, although 12 to 14 mm Hg is recommended. It would be best to try to operate at the lowest IAP possible with the lowest flow rate to accomplish the planned surgery and not use arbitrary numbers because they may exceed safety limits in a particular patient.[1–3]

IAP causes a mechanical event regardless of the chemical formula of the gas(es) involved. The safety profile of CO_2 favors its use and has chemical effects separate from the generalized mechanical effects of any pneumoperitoneum. Any gas(es) used for a pneumoperitoneum creates an increase in pressure and causes varying degrees of peripheral pooling, vena cava compression, increased venous resistance leading to decreased venous return, decreased cardiac output, and fluctuation in arterial pressure; increased intrathoracic pressure; peritoneal receptor stimulation with neurohumoral factor release of vasopressin, catechols, and renin; and increased vascular resistance of intra-abdominal organs, which increases systemic vascular resistance, acidosis, hypercarbia, hypoxia, and oxidative stress, and—if the gas dissects into surrounding tissues—pneumothorax, pneumomediastinum, and subcutaneous emphysema (**Table 2**).[4]

The ideal gas for pneumoperitoneum insufflation is nontoxic, colorless, readily soluble in the blood, easily expelled from the body or expired through the lungs, nonflammable, and inexpensive. CO_2 best satisfies these characteristics. Oxygen and air are not readily absorbed through the peritoneum and can result in air embolism. Nitrous oxide (NO) has unpredictable absorption. Helium (He) is relatively insoluble in blood compared with CO_2. Argon (Ar) has a more significant depressant effect on hemodynamics than CO_2. Oxygen and NO, if mixed with methane, support com-

Table 2.
Recognizable Changes Seen with Subcutaneous Emphysema

Crepitus

Insufflation problems (flow and pressure)

Hypercarbia (monitor end-tidal CO_2)

Acidosis (monitor partial pressure of CO_2 in arterial blood and rule out malignant hyperthermia)

Change in lung compliance

Cardiac arrhythmias, sinus tachycardia, and hypertension

Intraoperative increase in partial pressure of end-tidal CO_2 >50 mm Hg

bustion and are dangerous. The best elements of safety, utility, and cost favor the use of CO_2.[5,6] The rate of CO_2 absorption through the peritoneum during laparoscopy ranges between 14 and 48 mL/min[7] based on peritoneal cavity gas clearance estimates and on peritoneal blood flow being between 2% and 7% of cardiac output, to be ~100 mL/min (**Table 3**).[8–10]

The incidence of subcutaneous emphysema varies from isolated and confined in a small space to extravasation outside of the abdominal cavity extending into the labia, scrotum, legs, chest, head, and neck. The literature range is 0.43% to 2.3% for grossly detectable subcutaneous emphysema. It has been shown in postoperative computed tomography scans from laparoscopic cholecystectomy patients that there was a 56% rate of grossly undetectable or clinical subcutaneous emphysema 24 hours after the procedure.[11]

Pneumothorax caused by extension of insufflated gas through diaphragmatic congenital channels into the pleural cavities is reported as 0.03%.[12–14] Subcutaneous emphysema, pneumomediastinum, and retroperitoneal extravasation without pneumothorax have also been described during laparoscopic surgery with CO_2 insufflation and may be associated with prolonged hypercarbia.[15] Recent articles citing use of a valveless trocar and dynamic pressure system (Air-Seal; SurgiQuest, Milford, CT) showed a 16.4% rate of subcutaneous emphysema over 6.3 times the reported rate, a 3.9% rate of pneumomediastinum 2 times the reported rate, and a 0.9% complication rate of masked pneumothorax a rate 2.3 times the reported rate for a 21.24% total overall complication rate or 4.3 times the total reported rate.[16–20] Because of these dangers and increased rates of occurrence, it is important that physicians who perform laparoscopy and the postoperative treatment of these patients be familiar with these complications, their natural history, and their management.

The clinical significance of subcutaneous emphysema is development of hypercarbia and acidosis. The increased

Table 3.
Intraoperative Causes and Risk Factors for Hypercarbia During Laparoscopy

Integrity of the anesthesia circuit
Position and function of the endotracheal tube
Inadequate respiratory exchange
Exclude causes other than CO_2 for acidosis
Underlying obstructive lung disease
Age >65 years
Type of surgery (Nissen fundoplication)

risk of hypercarbia is caused by the large peritoneal surface tissue area exposed to CO_2.[21,22]

Hypercarbia and acidosis are the most commonly recognized complications. A combination of factors contribute to increased arterial partial pressure of CO_2 in arterial blood: rapid absorption of CO_2, reduced diaphragmatic movement, a decrease in residual functional capacity, and decreased pulmonary CO_2 excretion, leading to ventilation-perfusion mismatch.[23,24] Cardiovascular compromise can be caused by mechanical factors from increased intra-abdominal pressure, affecting ventilation and venous return and with accumulation of CO_2 in the circulation, leading to acidosis and cardiopulmonary system compromise.[25] Hypercarbia increases heart rate, systemic blood pressure, central venous pressure, cardiac output, and stroke volume, and it decreases peripheral vascular resistance because of the release of epinephrine and norepinephrine.[26–31]

Factors associated with subcutaneous emphysema during laparoscopic pneumoperitoneum are methods of laparoscopy (video assisted or robotic),[32] insufflator settings for pressure and flow, actual IAP, actual flow rate, number of abdominal entry sites, size and geometry of fascial incision to trocar size of entry site, snugness of fit between trocar and fascia, number of times the entry site is entered, amount of torqueing and pressure on entry sites, vectoring of the laparoscope, fulcrum effect between laparoscope and fascia, length of procedure, volume of gas used, patient age, patient BMI, coexisting metabolic diseases, tissue integrity, type of trocar used, and purposeful extraperitoneal dissection. The total amount of gas used may or may not be related to the length of time of the procedure and may be more important than the length of time of the procedure. Insufflator settings for pressure and flow rate influence insufflation dynamics, the amount of gas absorption or extraperitoneal extravasation with higher pressures, and flow rates contributing to the increased incidence of gas extravasation, noted as *subcutaneous emphysema* (**Table 4**).

Forces, Fulcrum, and Leverage

How and to what extent a tissue is dissected by gas depends on its structure, integrity, composition, architecture, morphology, tensile strength, and adherence to underlying structures. These tissue characteristics are affected by the pressure settings, pressure drop, volume, duration, and resistance to gas flow. Peritoneal separation can occur because of multiple repetitive movements of the laparoscope acting through a can-

Table 4.

Factors Associated with Increased Likelihood of Subcutaneous Emphysema, Pneumothorax, or Pneumomediastinum

Improper placement of gas

Repeated attempts to create a pneumoperitoneum

Improper placement of the trocar

Loose trocar fascia entry

Number of trocars >4

Size of trocars is ≥10 mm

Torqueing with traumatic expansion of the fascia

Longer surgery time

Volume of gas (must be recorded and part of the record)

Flow rate and pressure (high flow rate and high pressure)

Lack of external visualization during robotic procedures

Lack of haptic feedback during robotic procedures

Increased mechanical advantage without recognition during robotic surgery

nula. The cannula acts as a fulcrum for the laparoscope (lever arm) to act as a class-one lever and force multiplier. The pivot point is the fascial entry site. The resulting mechanical advantage can extend the original peritoneal penetration site, allowing gas extravasation into planes outside of the abdomen. During robotic surgery, instrument manipulation occurs without the surgeon's ability to sense or appreciate these forces because of lack of haptic feedback and the inability to see the relationship of the length of the laparoscope to the abdominal entry point. Separation of the surgeon at a console from the patient removes the ability to see the results of their hand movements and how this effects trocar angle and amount of stress and torqueing of the peritoneal entry site, because there is little to no haptic feedback (tactile) to alert the surgeon of overstressing the port entry sites. Attention of the assistant at the operating table is important for monitoring not only the robotic instruments but also the entry sites and robotic movements that may compromise the port sites.

A laparoscope or instrument placed through the abdominal wall into the peritoneal cavity acts as a class-one lever with the fulcrum pivot point as the trocar and fascia. The laparoscope is the movable bar pivoting at the fixed point of the trocar and fascia. Because distance from the fulcrum equals force × distance, this becomes leverage and thus mechanical advantage. The laparoscope becomes a force multiplier. A small force a long distance from the fulcrum can produce a significant effect. The laparoscopy through the cannula also creates torque and a vector pressure by fulcrum effect on all tissue structures in that path. Torque is the force causing an object to rotate about an axis, fulcrum, or pivot. The laparoscope rotates about an axis or pivot point as it passes through the cannula, penetrating the abdominal wall. The distance from the pivot point to the point where the force acts is the moment arm, creating a vector that can increase the size of the peritoneal entry defect.

Torque pressure sensation can be appreciated during traditional straight laparoscopic procedures but is not felt during robotic procedures, because there is a loss of force feedback and haptic awareness. During robotic procedures, force feedback related to angulation of instruments and trocars and lack of direct visualization of the cannula by the operating surgeon increases the potential for overstressing tissues and loss of tissue layer integrity, which leads to gas extravasation tissue dissection and subcutaneous emphysema.

Literature Review of Subcutaneous Emphysema and Laparoscopy

A search of PubMed for "subcutaneous emphysema" and "laparoscopy" identified 175 citations.[7,33–65] Major contributors to the occurrence of subcutaneous emphysema include surgical entry technique leading to preperitoneal insufflation, improper trocar placement, gas flow rate and pressure setting, number of trocars, length of procedure, and total amount of gas used.[33–39]

The reported incidence rate of known subcutaneous emphysema ranges from 0.43% to 2.34%.[7,33,40] It is reported that as much as 77% of laparoscopy patients have grossly undetectable subcutaneous emphysema but 20% have findings on postoperative chest radiograph of pneumomediastinum.[36–38] Computed tomography scans taken within 24 hours of laparoscopic cholecystectomy show 56% of patients with undetectable subcutaneous emphysema.[41] Prolonged operative time, increased age, increased end tidal carbon dioxide, and increased number of operative ports are significantly associated with subcutaneous emphysema.[32] None of the articles reviewed evaluated, screened for, measured, or mentioned total gas volume as a consideration regarding correlation or association with subcutaneous emphysema occurrence. Of course, the gas is necessary for the occurrence so gas volume is a necessary component and important factor. Overlooking or disregarding total gas volume is a disregard for completeness and appreciation of the laparoscopic process: this is a critical flaw in the assessment of the activity. Historically, there is little to no appreciation of the interaction, correlation or lack of correlation, causa-

tion, or association and the relationship between the amounts of gas used during laparoscopy, length of time of insufflation exposure, or the IAP during the surgery. The relationship of gas volume and subcutaneous emphysema occurrence is the interaction of gas volume used, insufflation exposure time, gas flow rate, and IAP. Subcutaneous emphysema is caused by the constellation of these factors. There is at least a matrix of 16 possibilities. It could be low gas volume, increased surgery time, high sustained intra-abdominal pressure and high gas flow, or high total gas volume, long surgery time, high IAP and low gas flow rate, or large gas volume, short exposure, high IAP, and high gas flow rate, etc. Based on the literature, the contribution of these factors is unknown. The data point of CO_2 volume for laparoscopic procedures is mostly ignored, poorly monitored, and rarely recorded or reported. Not paying attention to this is folly and sloppy, and it disregards a factor that has an impact on and consequences for the patient. The question is how much gas exposure, along with other factors, causes extravasation? Insufflation time is usually noted on the anesthesia record; pressure and volume settings may or may not be charted, but total gas exposure volume is universally *not* recorded. It is suspected that the factors of gas flow, length of gas exposure, IAP, and gas volume used affect the patient and the occurrence of gas extravasation and subcutaneous emphysema (**Table 5**).

To reduce the likelihood of subcutaneous emphysema, the following are recommended: awareness of its potential; physician vigilance; attention to detail regarding abdominal entry; monitoring insufflator settings for pressure, flow rate, and volume of gas with alarm settings; quickness, but not rushing, to complete the procedure (because length of procedure and gas consumption relate to the condition); reduce the

Table 5.
Actions to Initiate When Subcutaneous Emphysema Is Suspected or Noticed

Evaluate for a pneumothorax

Check end-tidal CO_2 and arterial CO_2

Increase ventilation rate and tidal volume

Increase oxygen to 100%

CO_2 absorber in the circuit

Decreased IAP

Discontinue NO because it rapidly enters the area of tissue emphysema

Assess airway to ensure there is no compression before extubation

Table 6.
How to Prevent Subcutaneous Emphysema

Awareness

Vigilance

Observation

Technique

Low gas flow and pressure settings

Low IAP

Cannulas that fit snugly

Gentle handling of trocars intraoperatively

CO_2 gas monitoring (respiratory and blood)

Reduced torqueing and fulcrum effect

Performing quickly, but not rushing

Attention to detail, attention to detail, attention to detail

number of attempts to enter the abdomen; have a snug trocar skin condition; test for correct placement by initial IAP assessment; and monitor end tidal CO_2 (**Table 6**).

CONCLUSIONS

See **Tables 1–6.** Factors that should alert surgeons and anesthesiologists to the potential for subcutaneous emphysema are the use of four or more trocars, trocars that are not tight fitting with slippage, prolonged increases of IAP, increased operating time, and increased volume of gas. It is necessary to be prepared for less than optimal occurrences during laparoscopy, have a plan, be vigilant, be cautious, know how to use and set the insufflator, record the volume of CO_2 gas used, use the fewest number of cannulas to perform the surgery, make the cannula skin/fascia entry a tight/snug fit, use the lowest flow rate and IAP that allows the planned surgery to be performed safely, know the limitations of the instruments and how they can be misused, place cannulas at angles appropriate for the surgery planned, be aware that the laparoscopy can act as a lever with mechanical advantage, keep IAP <15 mm Hg, monitor end-expiratory CO_2, look at and feel the skin around the cannula insertion sites, perform the surgery quickly but not hurried, and, finally—attention to detail, attention to detail, attention to detail.

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