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Narrative Review

Venous carbon dioxide embolism during laparoscopic cholecystectomy a literature review

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ABSTRACT

Laparoscopy has become the procedure of choice for routine gallbladder removal. A serious complication of this technique is the occurrence of gas emboli due to insufflation. It is associated with a high mortality rate of around 28%. The present systematic review intends to provide more insight into causes, symptoms and risk factors for this specific complication and to explore which measures should be taken to treat and prevent it. The Cochrane library and Pubmed were used as sources. Articles and their references were selected when they were related to the subject in sufficient detail.

The course of this complication can vary from asymptomatic up to impairment of normal flow through the right ventricle (RV) or pulmonary artery, potentially leading to acute heart failure. The severity depends on the amount of gas, the rate of accumulation and the ability to remove the gas bubbles. It is difficult to estimate the true incidence of venous gas embolism during laparoscopic cholecystectomy as there are various diagnostic tools, each with different sensitivity. Precautions that need to be taken are: correct positioning of the needle, low insufflation pressure, low insufflation speed, screening for hypovolemia, Trendelenburg positioning, availability of intervention equipment at operation table, no placement of venous catheters during inspiration and catheter removing during expiration.

Physicians need to be more aware of this harmful complication and the preventative measurements that need to be taken. As there are virtually no prospective data, future studies are needed to gain more knowledge on gas emboli during laparoscopic cholecystectomy.

1. Introduction

Laparoscopy has become the procedure of choice for routine gallbladder removal and is currently the most commonly performed major abdominal procedure in Western countries [1]. In comparison to open cholecystectomy, laparoscopic cholecystectomy is a minimal invasive procedure. Advantages of this technique are less postoperative pain and a faster recovery [2]. The most common complications that can occur are duct injury, bile leaks, bleeding, and bowel injury. These complications are, at least in part, related to patient selection, surgical (in) experience, and the technical restrictions that are inherent to the minimally invasive approach [3].

A less common but nonetheless not less harmful complication is the occurrence of gas emboli due to the formation of a pneumoperitoneum. This complication may result in blockage of blood flow through the right ventricle (RV) or pulmonary artery and this may even lead to acute heart failure [4]. This complication is associated with a high mortality rate of around 28% [5].

The most common cause of a carbon dioxide embolus is the incorrect injection of the Veress needle into a large vein or artery, or into a highly vascularized solid organ [4]. The latter is seen mainly during insertion of the Veress needle into the liver because the hepatic veins do not collapse as much as other systemic veins. This complication usually occurs during or shortly after insufflation of carbon dioxide into the body cavity due to disruption of the integrity of the vascular wall but may also result from direct intravascular insufflation of carbon dioxide during surgery.

Recently, we encountered a patient who was scheduled for

Abbreviations: CVP, Central Venous Pressure; ETCO2, End Tidal Carbon Dioxide; ETN2, End Tidal Nitrogen; HBOT, Hyperbaric oxygen therapy; mPAP, mean Pulmonary Artery Pressure; PEEP, Positive End Expiratory Pressure; SvO2, Mixed Venous Oxygen Saturation; TEE, Trans Esophageal Echocardiography; TTE, Trans Thoracic Echocardiography

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laparoscopic cholecystectomy because of cholecystolithiasis but went into cardiac arrest following carbon dioxide gas embolism. She survived after immediate desufflation of the body cavity and resuscitation. This observation prompted us to review the literature in order to identify causes and risk factors for this specific complication and to explore which measures should be taken to prevent it.

Using a time filter of ten years, we searched the literature with the Cochrane library and Pubmed as sources and using the following search terms: (((((“Laparoscopy”[Mesh]) OR laparoscopic cholecystectomy) OR insufflation)) AND (((“Accident Prevention”[Mesh]) OR prevention) OR improvement)) AND ((((embolism) OR ‘carbondioxide embolism’) OR ‘CO2 embolism’) OR “Embolism, Air”[Mesh]).

Of the eighty-eight articles that we retrieved with this search strategy, we individually selected the papers that contained information in sufficient detail to allow inclusion in our analysis. This resulted in seventeen eligible articles. Seventy papers were not suitable for our review for the following reasons: venous embolism, surgical techniques other than laparoscopy and surgical sites other than abdominal surgery. The references of the seventeen selected articles were also independently analyzed for useable articles. This yielded another thirty-seven papers, making a total of fifty-four hits.

1.1. Incidence

In one prospective study, gas embolism was detected by transesophageal echocardiography (TEE) in 11 out of 16 patients. In five of these, the embolism was seen during insufflation and in six during gallbladder dissection [6]. No significant difference was observed in cardiorespiratory variables between patients with and without gas emboli. In another study, however, no single case of venous embolization was found in 61 consecutive patients undergoing laparoscopic cholecystectomy. This study employed precordial Doppler ultrasound and end-tidal capnography to detect gas embolization which is a less reliable technique than TEE [7]. Indeed, when TEE was used to detect gas embolism during total laparoscopic hysterectomy, an incidence of even 100% was found [8]. This suggests that the very low incidence as reported in previous retrospective analyses such as the one by Bonjer et al. [9] markedly underestimated the occurrence of the complication, most likely because of inadequate diagnostic techniques.

1.2. Pathophysiology

Following inadequate insertion of a Veress needle, a carbon dioxide embolus can enter the circulation. This may cause serious pathophysiological effects, the severity of which depends on the amount of air that enters the circulation, the rate of accumulation of the bubbles and the ability of the body to remove the gas bubbles. The amount of carbon dioxide that enters into the circulation depends on the pressure or gravitational gradient between the vein at stake and the right atrium and thus on the position of the patient and that of the vein relative to the right side of the heart. No conclusive data are available with respect to the volume of air that is lethal in humans, although some case reports suggest this to be around 200 or 300 ml, or 3–5 ml/kg [10]. Other data showed a 60% mortality rate when carbon dioxide is infused at a rate of 1.2 ml/kg/min, which equals 84 ml/min in a 70 kg person [11]. Injection of 300 ml carbon dioxide into a 35 kg dog was the minimum amount of carbon dioxide for causing death [12].

As the embolus creates a gas lock effect, outflow from the right ventricle may be impeded, leading to acute heart failure, coronary ischemia and arrhythmias. In addition, microvascular function becomes progressively disturbed which may result in enhanced permeability of the vascular bed, activation of coagulation and a systemic inflammatory response [10]. Finally, pulmonary edema, bronchospasm and increased airway resistance may develop, resulting in hypoxemia and hypercapnia. If gas bubbles accumulate in the left ventricle (LV), diastolic filling of the coronaries will be jeopardized. All of this may result in circulatory collapse and even death [13].

Except for the effects of the embolus itself, the creation of the pneumoperitoneum could contribute to the development of serious complications. Indeed, a pneumoperitoneum impairs the excursions of the diaphragm and, thereby, reduces functional residual capacity of the lungs. In addition, compression of the inferior caval vein may occur which in some cases will reduce venous return and preload of the heart to such an extent that hypotension will follow. The subsequent activation of the sympathetic system will cause systemic vasoconstriction with a stagnant blood flow and arrhythmias [14].

1.3. Risk factors

As summarized by Shaikh and Ummunisa, risk factors for the occurrence of a gas embolism involve: operative site more than 5 cm above the right atrium, operation site with numerous venous channels, barotrauma causing alveolar rupture into a small vein and fracture or detachment of the catheter [15]. The creation of a pressure gradient for air entry into the circulation also forms a risk factor. For instance, a study in piglets showed that the risk of gas embolism during laparoscopic liver resection was significantly greater at a high intra-abdominal pressure of 16 mmHg as compared to 8 mmHg [16]. Particularly in patients with primary biliary cirrhosis or other diseases of the biliary track, the risk may be enhanced as a consequence of an upregulated angiogenesis which is often seen in such patients. The formation of more blood vessels due to angiogenesis increases the risk of inserting the Veress needle incorrectly [17]. Finally, unanticipated anatomical variations, such as a patent paraumbilical vein, may increase the risk of gas embolism [18]. To what extent such risk factors contribute to the risk of carbon dioxide embolism during laparoscopic cholecystectomy, is presently unknown.

1.4. Signs and symptoms

Signs and symptoms that may be found after inaccurate needle insertion vary with the amount of air that has been injected into the circulatory system and the location of the embolism. Patients may be either asymptomatic or experience mild symptoms or suffer from complete cardiovascular collapse. In this regard, it is uncertain whether the high incidence of emboli as discovered by TEE has any clinical relevance, because many emboli may be entirely asymptomatic and/or without clinical sequelae.

A myriad of clinical signs and symptoms have been described among which are chest pain, wheezing, breathlessness, bronchoconstriction, cyanosis, jugular venous distension, right heart failure, tachycardia, bradycardia, arrhythmia, asystole, hypotension, altered mental status, and cardiovascular collapse. A “mill-wheel” murmur may be heard during auscultation and the ECG may reveal ST-changes and peaked P-waves [10]. Sometimes, a Babinski sign is present which is associated with a poor prognosis [19]. Unfortunately, we do not know precisely how often all these symptoms occur.

1.5. Diagnosis

For the detection of air emboli, TEE can be used. One study found that TEE was able to detect, during venous injection of air, an embolus already at a threshold dose of 0.02 ml/kg [20]. This makes TEE the most sensitive, albeit somewhat invasive, monitoring modality for air embolism. Doppler ultrasound is the second most sensitive non-invasive monitoring technique, that is capable of detecting air emboli of 0.05 ml/kg of air.

Transthoracic echocardiography (TTE) can also be used for diagnosing gas embolism. TTE is a more convenient diagnostic tool but it is less accurate than TEE and often fails to detect the embolus [4,21]. When one uses a pulmonary artery catheter, an increase in the PAP (Pulmonary Artery Pressure) may indicate the presence of an air

Table 1
summary of threshold bolus for positive response of diagnostic tool for venous injection of gas.

Diagnostic tool	Number of patients	Threshold bolus venous injection of gas for positive response	Reference
TEE	N = 6 or N = 8 (pigs)	0.02 ml/kg or 0.26 ± 0.24 ml/kg	Furuya et al., Couture et al. [20,23]
Doppler ultrasound	N = 6	0.05 ml/kg	Furuya et al. [20]
ETCO2	N = 8 (pigs)	0.66 ± 0.51 ml/kg	Couture et al. [23]
ETN2		0.6 ± 0.25 ml/kg	Frost, E. (2013). Clinical Anesthesia in Neurosurgery. 3rd ed. Burlington: Elsevier Science, page 232.
MPAP	N = 8 (pigs)	0.76 ± 0.33 ml/kg	Couture et al. [23]
SvO2 in fiberoptic pulmonary artery catheter		1 ml/kg	Frost, E. (2013). Clinical Anesthesia in Neurosurgery. 3rd ed. Burlington: Elsevier Science, page 232.

embolus. Also an increase in the ETN2 (end-tidal nitrogen) and a rapid increase followed by an abrupt decrease in ETCO2 (end-tidal carbon dioxide) are indicative of this complication [10,22]. Finally, pulse oximetry may show a lower oxygen saturation as a sign of embolism.

Table 1 summarizes the threshold boluses for a positive response of a diagnostic tool during venous injection of gas.

1.6. Treatment

Whenever there is a clinical suspicion of a venous air embolism, immediate action is necessary to prevent further entrainment of air and to stabilize the patient. The pneumoperitoneum needs to be released to prevent further embolization [24]. Subsequently, the surgeon may perform the Durant's maneuver which implies that the patient is placed in left lateral decubitus or Trendelenburg position. This way, the air bubbles are more likely to move out of the right ventricular outflow tract (RVOT) and into the right atrium, thus reducing the risk for an “air-lock”. There is, however, no evidence in humans that this maneuver is truly beneficial. Mirski et all. [10] stated that the use of the Durant's maneuver in animas is proven not to be beneficial regarding hemodynamic stability. Durant's maneuver only seemed to be profitable regarding the shift of air into a less risky portion of heart.

Moreover, in case of an arterial air embolism, patients need to lay in a flat supine position, because otherwise the Durant's maneuver may induce or increase cerebral edema [25].

Some sources recommend gas evacuation via a central venous or pulmonary artery catheter. In one study, a maximum of 50% of the entrapped air could be aspirated [26]. However, a smaller effect is more likely due to the placement of the catheter and the patient's position. This might be due to the narrow luminal diameter and so the highest chance of success is when there already is a catheter near the right atrium or ventricle.

Hyperbaric oxygen therapy (HBOT) provides the patient with 100% oxygen at a positive pressure. In a venous but also arterial gas embolism it helps to reduce the size of the air bubble, increases oxygen content of the blood, hence increasing tissue oxygenation via diffusion [27,28]. The size of the bubble is inversely proportional to the atmospheric pressure, so by applying more than 1 atm, the bubble size shrinks [29].

Experimental data suggest that High Frequency Jet Ventilation (HFJV) may also be applied in the treatment of venous gas emboli [30] but reliable data on its effects in humans are lacking.

If necessary, cardiopulmonary resuscitation is performed. Resuscitation may help the migration of the embolus into the pulmonary system from which it can be exhaled. Resuscitation also promotes end-organ perfusion in this critical situation.

Studies show that anticoagulation therapy prior to the embolization reduces the severity of the complication [15].

1.7. Prevention

For the prevention of venous carbon dioxide emboli during laparoscopic cholecystectomy various precautions must be considered. First of all, correct positioning of the Veress needle needs to be assured. For this maneuver it is also important to avoid repeated insertions and removals of the needle. The insufflation pressure and speed need to be low. A pressure between 8 and 12 mmHg is recommended for all laparoscopic surgeries to prevent cardiopulmonary complications [31].

Patients need to be screened for hypovolemia, because a lower central venous pressure (CVP) compared to the intraperitoneal pressure is associated with a higher risk.

During insufflation the cardiac rhythm must be actively assessed for changes that may point to the occurrence of an embolism [32].

It is also important to place the patient in Trendelenburg position as a head-down position tends to reduce the risk of cerebral air emboli because the emboli are naturally buoyant.

Positive End Expiratory Pressure (PEEP) and HFJV have not proven to prevent the occurrence of a gas embolism [33].

Equipment such as central venous catheters material cannulas, resuscitation equipment and drugs need to be present in case when an intervention is needed [34]. Regarding the use of catheters there are some precautions that need to be taken. One should not place venous catheters during inspiration, because the negative intrathoracic pressure may increase the risk for gas emboli. When removing catheters, it is also recommended to raise CVP by keeping the patient in a supine position or with their head down or Trendelenburg position. The catheter needs to be removed during expiration. Furthermore, surgical experience and knowledge on possible air escape routes within these devices is recommended [29].

Gasses that are used for insufflation during laparoscopic surgery should be not flammable or explosive, be colorless, cheap, easily removed by the body and non-toxic. In this respect, an advantage of carbon dioxide is that an embolus, when this occurs, is rapidly processed and eliminated by the body. On the other hand, carbon dioxide can cause side effects such as metabolic acidosis, hypercapnia and cardiorespiratory complications.

Other gasses that have been used during laparoscopic operations are: argon, nitrogen and helium. Findings show that argon gas may have unwanted side effects, especially on systemic and hepatic hemodynamics [35,36]. Nitrogen gas dissolves rather slowly. It may play a role in some cases of depressed pulmonary function or in local/regional anesthesia cases. Helium also dissolves rather slowly and thus forms a greater risk at forming lethal venous emboli [37]. By and large, carbon dioxide still is the most preferable gas to use for insufflation and there are no other gasses that could possibly reduce the risk of an embolization.

2. Conclusion

This present systematic review intends to summarize available data on carbon dioxide emboli formation during laparoscopic cholecystectomy. Proper knowledge on this complication may help to improve patients' safety during this procedure.

The goal of creating a pneumoperitoneum during laparoscopic cholecystectomy is to optimize visualization for the surgeon. However, a potential drawback of pumping air into the peritoneal cavity is that a gas embolism may develop. Such can happen when the Veress needle has been inserted inaccurately or (when occurring shortly after insufflation) a possible entry for the embolism into the vascular system exists. Because the incidence of clinically relevant gas emboli is relatively low, operators may not always be fully aware of the signs, symptoms, treatment and prevention of this complication. Consequently, this leads to a greater risk of mortality and morbidity.

The severity of the complications depends on the amount of air injected into the circulation and on the ability to eliminate the gas via the lungs. Carbon dioxide emboli can lead to a gas lock effect, which produces marked hemodynamic instability and, in severe cases, even circulatory collapse and death. There certainly are risk factors that can contribute to the formation of a gas embolism, but to what extent they contribute to this risk is yet unknown.

Uncertainty exists also with respect to the question which equipment should be used to diagnose gas embolism. Although TEE undoubtedly is the most sensitive method, it will detect many, clinically irrelevant emboli, and may, therefore, lead to overzealous and unjustified treatment. There is a need, therefore, to better establish the sensitivity and specificity of the available diagnostic tools. As such an assessment would be hardly possible in patients, an alternative solution could be to combine in a large group of patients who undergo laparoscopic procedures hemodynamic monitoring with imaging data so that, in retrospect, we may be able to better correlate the results from such measurements.

For the prevention of gas embolism several precautions need to be taken: correct positioning of the Veress needle, low insufflation pressure and placement of the patient in Trendelenburg position, although the latter is not without debate. Patients need to be screened for volume status, because hypovolemia increases the risk for gas emboli. The cardiac rhythm also needs to be closely monitored before and during surgery to pick up early signs of embolization. Central venous catheters, resuscitation equipment and supportive drugs need to be available during this intervention. Perhaps even other preventive measures are necessary for other laparoscopic procedures than laparoscopic cholecystectomy but that cannot be derived from the literature reviewed here.

Declarations of interests

None.

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