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Complications of robotic and laparoscopic urologic surgery relevant to anesthesia

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Abstract

Technology keeps advancing in this era allowing surgery to become less invasive in many surgical sciences. Besides these technological advances, minimally invasive procedures such as laparoscopy and robotic assisted laparoscopy are preferred widely around the globe by both surgeons and patients. Because of the increasing demand to laparoscopy and robotic surgery, anesthetists also should adapt to these specific surgical procedures. Carbon dioxide (CO₂) insufflation is applied in these procedures in order to provide working space and exposure to target organs. CO₂ insufflation (pneumoperitoneum if applied intrabdominally) and positional maneuvers such as steep Trendelenburg position is used in urologic laparoscopy and robotic surgery, which have vital effects on patient's physiology regarding cardiovascular, respiratory, renal, ocular and neurological systems. Special positions and unique surgical tools used in these procedures may hinder vital interventions such as cardiopulmonary resuscitation and open conversion. Comprehension of these pathophysiological effects and specific considerations is crucial to detect, to prevent and to manage serious complications that may occur during surgery.

Keywords: Anesthesia, complications, laparoscopy, pathophysiological changes robotic surgery, urologic surgery

INTRODUCTION

Minimally invasive surgery is now being applied more and more frequently in urology practice as it is in other surgical sciences. With the advances in technology, robotics had started to be used in surgery and robotic surgery followed the widespread use of laparoscopic surgery. Many oncological and reconstructive surgical operations are performed worldwide with laparoscopic and robotic assisted laparoscopic surgery.



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Although the aim of the procedures and the results obtained with the application of laparoscopic surgical techniques seem similar, the physiological effects of laparoscopy are very different from open surgery; therefore minimal invasive surgery certainly requires a specific anesthetic management^[1,2]. For laparoscopic and robotic assisted laparoscopic operations, pneumoperitoneum is essential to provide the working area. The most common gas to provide the pneumoperitoneum is carbon dioxide (CO₂). The metabolic profile created by the absorption of CO₂ gas and the effect of abdominal or retroperitoneal high pressures, especially on the respiratory and circulatory system, can compromise the anesthetic management of laparoscopic procedures^[3]. This becomes even more complicated in operations where steep Trendelenburg position is combined, such as robotic radical cystectomy and robotic radical prostatectomy. Combination of pneumoperitoneum with steep Trendelenburg position in these operations may increase the risk of hemodynamic, respiratory and hemostatic disorders^[3-5]. In order to provide the proper management of the patient undergone a laparoscopic or robotic assisted laparoscopic surgery and avoid the complications; one must thoroughly understand the effects of CO₂ pneumoperitoneum and Trendelenburg position.

PATHOPHYSIOLOGICAL EFFECTS OF PNEUMOPERITONEUM AND TRENDELENBURG POSITION DURING LAPAROSCOPY

For an adequate working space and exposure to the target area of the operation, initially pneumoperitoneum is provided and usually CO₂ gas is used for the procedure. Pressure levels change between 12-15 mmHg in most cases. However up to 20 mmHg pressures are reported in the literature^[4]. CO₂ insufflation is applied through a Veress needle or through a trocar if open Hasson technique is used. In some procedures such as robotic radical prostatectomy or robotic radical cystectomy, applying Trendelenburg position may also be mandatory because the intestines might obscure the vision. In order to have adequate exposure; the bowels must be removed from targeted area of surgery by applying Trendelenburg position. But pneumoperitoneum (both by increasing the intra-abdominal pressure and by causing hypercarbia) and Trendelenburg position itself has considerable effects on cardiac, pulmonary, renal and cerebrovascular physiology^[5-7].

Effects of carbon dioxide absorption

With the beginning of insufflation CO₂ gas starts to fill the cavity where the operation will be carried on. It is highly diffusible in the body and highly soluble in blood. CO₂ exposure may lead to hypercarbia. Hypercarbia increases with higher pressures and longer exposure times^[7]. The respiratory system is the major way to excrete the CO₂. Pneumoperitoneum with high intrabdominal pressures and Trendelenburg position may affect the excretion of CO₂. Therefore, higher CO₂ pressure both increases the absorption and decreases the exhaustion. The dissolved CO₂ in blood increases H⁺ ions and causes acidosis. Hypercarbia and acidosis decrease the cardiac contractility, make myocardium more sensitive to catecholamines and cause peripheral vasodilatation. But with the sympathetic activation caused by hypercarbia it finally leads to tachycardia and vasoconstriction^[8]. During laparoscopic or robotic operations in urology both transperitoneal (TP) and extraperitoneal (EP) techniques are used. Although both approaches seem to have similar consequences there are minor differences observed during CO₂ insufflation. In their research comparing the effects of CO₂ insufflation on hemodynamics, oxygen levels and acid-base homeostasis in TP vs. EP robot-assisted laparoscopic radical prostatectomy (RALRP), Dal Moro *et al.*^[9] reported that, EP approach causes a higher absorption of CO₂, thus a more rapid acidosis. Although in both approaches there were similar operative times and there was even a less extreme Trendelenburg position in EP approach, EP RALRP was more relevant with CO₂ absorption and acidosis. A similar study by Meininger *et al.*^[10] also reports that CO₂ absorption was more pronounced with EP approach than TP. However the reasons for these consequences seem to be multifactorial and have not been yet clarified^[9].

Pneumoperitoneum and Trendelenburg position

TP approach is frequently preferred in urological surgery as it provides a familiar anatomic perspective to the surgeon and it is thought to be an easier technique to master at. However, EP approach may also be

preferred, and both techniques have advantages and disadvantages. CO₂ insufflation to abdominal cavity creates pneumoperitoneum. CO₂ insufflation makes considerable pathophysiological effects by causing hypercarbia and acidosis. Apart from that pneumoperitoneum increases intra-abdominal pressure (IAP) which may cause serious cardiovascular, respiratory and neurological effects^[5-7,11-13]. Trendelenburg position also effects negatively by decreasing pulmonary compliance and functional residual capacity^[14-16].

Effects on cardiovascular system

The effects of pneumoperitoneum on hemodynamics is highly depended on the level of IAP, and patient position^[12]. With the initiation of pneumoperitoneum mean arterial pressure (MAP) and systemic vascular resistance (SVR) increase > 25% and 20% respectively, however SVR returns to basal after providing Trendelenburg position^[17]. Increased IAP decreases the venous return and cardiac output but Trendelenburg position reversely increases the venous return and it may neutralize this effect^[18]. But of course these effects alter with the level of IAP. IAP lower than 15 mmHg causes increase in cardiac output by applying pressure to splanchnic venous bed and sympathetic stimulation caused by hypercarbia contributes by providing peripheral vasoconstriction and increasing cardiac motility. On the other hand IAP > 15 mmHg applies compression over inferior vena cava and preload decreases causing hypotension^[18]. Another significant factor in laparoscopy that has effect on hemodynamics is vagal stimulation. Vagal stimulation may be initiated by peritoneal expansion caused by pneumoperitoneum, by direct stimulation of peritoneum with Veress needle or trocars or as a result of gas embolism (CO₂ embolism)^[19]. Vagal stimulation may cause bradyarrhythmia (in a range from bradycardia to asystole) and hypotension^[7,20]. Tachyarrhythmia may also be experienced as a result of sympathetic activation caused by hypercarbia^[8]. The effects of pneumoperitoneum and Trendelenburg position on hemodynamics are usually well tolerated in patients with normal cardiac function, but it has been reported that even in elderly patients with ASA 2-3 risk or even in patients with underlying heart conditions such as aortic stenosis, laparoscopic operations may still be safely performed with adequate monitoring and being aware of possible complications^[21,22]. High insufflation pressures and hypercarbia caused by long operative times or CO₂ venous embolism increases the risk of cardiovascular complications.

Effects on respiratory system

During laparoscopy insufflation increases IAP which causes an increase in peak airway pressures and a decrease in lung volumes and pulmonary compliance^[23]. Particularly in operations such as RALRP or robotic cystectomy cephalad shift of diaphragm related to high IAP gets more severe by the addition of Trendelenburg position, because the abdominal contents push the diaphragm^[23]. Eventually atelectasis may occur and functional residual capacity may decrease and a ventilation-perfusion mismatch may develop. These changes may lead to hypercarbia and hypoxemia. Moreover, high IAP increases the risk of barotrauma which may lead to pneumothorax or pneumomediastinum. These effects on respiratory system do not immediately return to normal postoperatively. Studies show that regaining full function of lungs may take 5 days postoperatively in patients without pulmonary disease, while it may take more than 5 days in patients with chronic obstructive pulmonary disease (COPD)^[16]. Therefore patients with COPD should be advised to continue pulmonary rehabilitation even after being discharged.

Effects on neurological system

Pneumoperitoneum and Trendelenburg position are both found to increase the intracranial pressure (ICP)^[5,13,24,25]. During pneumoperitoneum increased IAP prevents the venous return from lumbar venous plexus thus causing ICP to increase. Cerebral venous drainage is hindered and cerebral intravascular volume is increased. Due to these reasons ICP increases. Also combining pneumoperitoneum with Trendelenburg increases the ICP further and this may hinder cerebral oxygenation^[26]. Kalmar *et al.*^[27] examined patients undergoing RALRP which were exposed to prolonged steep Trendelenburg position and CO₂ pneumoperitoneum and suggested that it does not compromise cerebral perfusion. Though, it is advised to keep the patient in normocapnic range because regional cerebral oxygen saturation (rSO₂) is correlated with

the increase in partial pressure of CO₂ (PaCO₂). If the patient has already an increased ICP caused by various reasons or there is a risk of cerebral ischemia inducing with pneumoperitoneum and applying Trendelenburg position may cause no toleration due to ICP increase and severe cerebrovascular complications.

COMPLICATIONS AND MANAGEMENT

Pathophysiological changes during laparoscopy and robotic surgery has been already discussed. Most of these effects are well tolerated if a proper anesthetic care is provided in healthy patients. But even in healthy patients undesired consequences may be experienced. In order to prevent serious morbidity and mortality management of complications should be taken seriously and a coordinated crisis plan should be ready to be executed. Patients should be properly monitored to understand the current situation, to maintain stability and to avoid the complications with the necessary interventions on time. Standard monitoring includes electrocardiogram, non-invasive blood pressure, pulse oximetry, end tidal CO₂ concentration and urine output. Also in major surgery, hemodynamically unstable patients or in patients with cardiovascular disease intra-arterial blood pressure may be monitored by arterial cannulation^[21,28].

Cardiovascular complications

Cardiovascular complications related to laparoscopy begin to emerge with CO₂ insufflation. Hypotension, hypertension, arrhythmias and cardiac arrest may be encountered during laparoscopy. As the Trendelenburg position has the risk of increasing the risk of these complications, it may be wise to create the pneumoperitoneum in horizontal position rather than down-tilted^[12]. CO₂ insufflation and positional changes should be applied gradually as sudden changes may affect hemodynamic stability. Monitoring IAP is also mandatory, because it is one of the main reasons of changes on hemodynamics. Keeping the IAP low may allow avoiding many complications related to carboperitoneum. IAP > 15 mmHg increases cardiovascular risk as inferior vena cava is compressed and eventually preload decreases. Additionally atropine might be administrated before the initiation of pneumoperitoneum or it may be kept ready for administration to prevent the brady-arrhythmias related to vagal reflex^[12]. Acid-base homeostasis is instable in laparoscopic surgery because of the CO₂ insufflated and the decrease in pulmonary compliance. It is essential to monitor pH levels and PaCO₂ in order to keep the patient in normocapnic range and in ideal pH level, as it effects the cardiovascular efficiency and stability. If the patient has a cardiovascular disease the anesthetist should avoid using cardio-depressant drugs. If there is an increase in MAP due to increase in SVR, instead of increasing the concentration of inhalation anesthetics (which may cause myocardial depression, especially in patients with cardiovascular disease) administrating vasodilating agents reducing specifically preload or afterload should be considered^[21,28]. However studies report that even in cases which pneumoperitoneum is combined with steep Trendelenburg position (such as RALRP) a deterioration of cardiac function was not present and patients usually tolerate the changes well^[3,29]. However, the position and pneumoperitoneum may aggravate mitral deficiency, so it must be kept in mind if a mitral deficiency exists^[29]. If a cardiovascular complication is thought to be aggravated or caused by the position or pneumoperitoneum, first IAP should be decreased and if it does not work, CO₂ insufflation should be ceased, gas should be evacuated and position should be reversed to horizontal state. Venous gas embolism is a complication possible to occur during laparoscopic or robotic surgery that may have fatal consequences. It may occur during CO₂ insufflation or during surgical procedure especially if venous structures are involved. During insufflation if the Veress needle is inserted directly into vascular structures results may be much more catastrophic. If the structural integrity of a major vein is disrupted, the risk of gas embolism increases. But it does not have to be a major vein. During transection the dorsal venous complex in RALRP operations subclinical CO₂ gas embolism can be observed as reported in literature^[30,31]. The symptoms vary in a wide range; while most of gas embolisms are subclinical and can not be detected by standard monitoring, some might cause catastrophic consequences such as cardiovascular collapse^[11,23,30,31]. As it is a life-threatening matter, the anesthetist should be vigilant. In the presence of a gas embolism insufflation should be ceased

and the gas should be evacuated immediately. Left lateral decubitus position must be applied to prevent the gas from entering pulmonary artery. A central venous catheter should be placed for aspirating the gas and 100% O₂ hyperventilation and proper cardiopulmonary resuscitation should be applied.

Pulmonary complications

Possible pulmonary complications related to laparoscopy are hypoxemia, hypercarbia, barotrauma, pneumomediastinum, pneumothorax, atelectasis and pulmonary edema^[7,12,32]. As it is previously mentioned increased IAP in pneumoperitoneum causes an increase in peak airway pressures, a decrease in lung volumes and a decrease in pulmonary compliance. Trendelenburg position increases these effects further. These changes cause a ventilation/perfusion (V/P) mismatch and atelectasis. Eventually hypoxemia and hypercarbia may occur due to ineffective gas exchange. Hypercarbia and respiratory acidosis may be avoided by hyperventilation, which means 15%-25% increase in minute ventilation should be maintained^[12,33]. But during hyperventilation it is suggested to increase the respiratory rate and not the tidal volume; especially in patients with COPD, in patients with history of spontaneous pneumothorax or bullous emphysema; because high peak airway pressures and reduced pulmonary compliance may increase the risk of barotrauma and a spontaneous pneumothorax^[33,34]. Increase in minute ventilation may be provided by using both pressure-controlled ventilation and volume-controlled ventilation. Pressure-controlled ventilation was reported to decrease peak airway pressure and increase dynamic compliance and found superior to volume controlled ventilation by Assad *et al.*^[35]. But Balick-Weber *et al.*^[36] and Choi *et al.*^[37] reported that these two ventilation techniques are not superior to each other regarding respiratory mechanics and hemodynamics. Endo-tracheal intubation with either volume or pressure controlled ventilation is the recommended technique, especially for longer operations, because it provides a better control over CO₂ and prevents gastric regurgitation. But for shorter operations which can be performed at lower IAP levels, using conventional laryngeal mask airway (LMA) or a ProSeal® LMA (ProSeal LMA, San Diego, CA, USA) was found to be safe and effective in some laparoscopic gynecological operations and laparoscopic cholecystectomies; therefore it may be valid for laparoscopic urological operations without Trendelenburg position lasting < 2 h and performed at lower IAP levels^[38-40]. Increased IAP during CO₂ insufflation and Trendelenburg position may cause the distance between carina and endotracheal tube tip to become shorter leading to inadvertent endobronchial intubation and hypoxemia (due to ineffective ventilation)^[41]. Endotracheal tube's position should be checked regularly through the surgery and it should be checked if both sides are equally ventilated in order to avoid this complication. Patients without pulmonary disease usually tolerate side effects of pneumoperitoneum and Trendelenburg position well with proper anesthetic management and postoperative care^[23]. However, it may be more severe in patients with pulmonary dysfunction; so these patients must be carefully assessed preoperatively with pulmonary function tests and arterial blood gas analysis should be performed at preoperative evaluation and regularly during surgery through an artery cannula. If hypoxemia and hypercarbia persist even after proper interventions, pneumoperitoneum should be ceased and a slow re-insufflation should be applied or conversion to open surgery should be considered if necessary^[12].

Subcutaneous emphysema

Subcutaneous emphysema is the presence of gas in subcutaneous tissue passing through a disruption in peritoneum or through an inadvertent placed trocar. In a study conducted by McAllister *et al.*^[42] showed, up to 56 % of the patients after laparoscopic surgery had subcutaneous emphysema. However, this situation is mostly benign and is not serious. The clinical detection rate is between 0.3%-3% in laparoscopic surgeries^[7]. Subcutaneous emphysema may extend to mediastinum and pleura causing pneumothorax and pneumomediastinum, or vice versa it may be the sign of an extended pneumothorax or pneumomediastinum to subcutaneous tissue^[7]. Most of the cases with subcutaneous emphysema is clinically insignificant, however its relevance with pneumothorax and pneumomediastinum must be remembered. Also, if the neck is involved, obstruction of upper airways may be present. Risk factor for subcutaneous emphysema are multiple trocars, end tidal CO₂ levels higher than 50 mmHg, prolonged operative time and old patients^[43].

CO₂ gas reserved by subcutaneous emphysema may cause hypercarbia, so increased ventilation might be necessary to cope with the increased end tidal CO₂ concentrations.

Pneumothorax and pneumomediastinum

There are multiple ways for a pneumothorax to occur during laparoscopic surgery. Either a real pneumothorax may occur due to high airway peak pressures causing a congenital bulla to rupture or insufflated CO₂ may infiltrate thoracic cavity. Insufflated CO₂ may create a capno-thorax or capno-mediastinum (pneumothorax or pneumomediastinum caused by pure CO₂ that has been insufflated) through congenital or acquired (injuries caused by surgery) diaphragmatic defects, as a result of CO₂ dissecting through retroperitoneum or by the extension of subcutaneous emphysema up to pleura or mediastinum^[7]. Mostly the cases are asymptomatic and conservative treatment and close observation is sufficient. However increase in peak airway pressures, hypoxemia, hypotension and even cardiac arrest may be present according to the severity of this complication^[7,32]. If cardiopulmonary functions are compromised, releasing of pneumoperitoneum and placing a chest tube must be considered. Usually a chest tube insertion is sufficient^[44]. However thoracic complications after laparoscopic urologic procedures are rare and most of the cases are subclinical, thus a routine postoperative chest radiography was not found to be necessary^[44,45].

Renal complications

Due to high IAP in laparoscopic surgeries renal perfusion and glomerular filtration rate decreases thus causing oliguria^[46]. In multiple studies on animals and humans effects of pneumoperitoneum on renal physiology were examined and the reasons, which were found responsible for this complication, are IAP applying direct compression on renal vascular structures, activation of renin-angiotensin-aldosterone, increase of anti-diuretic hormone and low cardiac output^[47-49]. To prevent oliguria sufficient hydration of the patient before and during the operation must be provided and urine output must be observed especially in prolonged and major surgeries. Also using low-dose dopamine at 2 mcg/kg/min and nicardipine at 0.5 mcg/kg/min was found useful to protect kidneys from hypoperfusion and renal dysfunction^[50,51].

Neurologic complications

As previously discussed neurologic complications may occur due to laparoscopic and robotic surgeries as a reason of increase in ICP, cerebral hypoperfusion or hypoxemia. High risk patients with a previous cerebrovascular disorder should be carefully assessed preoperatively. Near infrared spectroscopy may be used to monitor cerebral oxygen levels. Pneumoperitoneum and Trendelenburg position both increases ICP^[13,24,25]. High ICP may cause transient or permanent neurologic deficits such as motor paralysis or paresis. In two case reports transient neurologic deficits including quadriplegia and hemiparesis were reported and both patients had full recovery^[52,53].

Ocular complications and edema

Trendelenburg position increases intra-ocular pressure. This may cause temporary or permanent loss in vision. Ischemic optic neuropathy, which is a rare complication, was reported after robotic and laparoscopic radical prostatectomy^[54]. Corneal abrasions may occur because of chemosis or exposure keratopathy^[55]. Eye patchings and transparent occlusive dressings are recommended to prevent corneal abrasions. Prolonged operations in Trendelenburg position may cause facial, periorbital, conjunctival, pharyngeal and laryngeal edema. Edema of the upper airways might cause serious consequences after extubation. If facial edema or conjunctival edema is observed, there is a chance that laryngeal edema might also exist. Therefore if there is a suspicion of upper airway edema, an endotracheal leak test should be done before extubation^[11].

Positional injuries and compartment syndrome

Patient positioning is an important preparation for the operation. Improper positioning may cause nerve injuries and compartment syndrome, furthermore it may compromise cardiopulmonary function^[12]. Mills *et al.*^[56] investigated positioning injuries associated with robotic surgery in their institution and

found that 6.6% of 334 patients had positioning injuries. These injuries resolved at least within 1 month but some persisted beyond 6 months^[56]. As well as positional effects caused by prolonged lithotomy and Trendelenburg, use of pneumatic compression stockings, intravenous fluid restriction for improvement of surgical view, hypotension and administration of vasoactive medication compromises the proper perfusion of lower extremity, thus increases the risk of compartment syndrome, especially in the lower extremities^[57,58]. Compartment syndrome of the upper extremities is relatively rare in the literature, however it is possible especially if higher amounts of intravenous fluid replacement is present^[58]. Galyon *et al.*^[58] reported a patient with compartment syndrome in three limbs including both lower extremities and left upper extremity after a robotic cystoprostatectomy which lasted about 6 h, and for treatment fasciotomy was performed to all affected extremities^[58]. In order to avoid this serious complication pressure points of the patient must be carefully assessed and materials absorbing the pressure must be placed between the body and operating table. Also repositioning of the extremities every 2 h was found to be beneficial avoiding compartment syndrome^[59].

Emergency situations

Due to the positions applied to patients and surgical equipment limiting the access to patients, critical interventions such as cardiopulmonary resuscitation or conversion to open surgery may delay. This may lead to lethal consequences. Life threatening emergencies like cardiopulmonary arrest require immediate attention and intervention. Especially in robotic surgery this may be a critical issue, as before the anesthesiology team could start a resuscitation, robot must be undocked. Simulating this situation and having an emergency plan can improve the time of preparation and intervention. O'Sullivan *et al.*^[60] experienced a respiratory complication during a robotic sacrocolpopexy. The patient had a decreased sPO₂ and increased airway pressure, thus an emergency undocking of the robotic arms was required. After this complication they reported that they created an emergency undocking protocol, which indicates the roles of each member of the crew in emergency situations^[60]. Also Huser *et al.*^[61] reported that proper training with repeating simulations improved the time for resuscitation in simulations. To be able to react to a life-threatening emergency swiftly, having a similar training and an emergency protocol may be useful.

CONCLUSION

Minimal invasive surgery is being increasingly more popular. The application of laparoscopic and robotic surgery is now more common. In urology, laparoscopy and robotic surgery may be applied in various operations including uro-oncological surgery. Minimally invasive surgery provides patients many benefits, however robotic and laparoscopic surgery also has a risk of many significant and unique complications related to these procedures. Pneumoperitoneum and specific patient positions such as steep Trendelenburg position have important physiological effects on cardiovascular, pulmonary, ocular, renal and neurological systems which may cause serious complications. In order to detect, manage or prevent these complications properly these physiological effects must be thoroughly comprehended. All personnel in the operating theatre should be prepared to all possible complications related to surgical procedure and anesthesia. With proper interventions, careful monitoring and preventive precautions, these complications may be avoided or at least their impact may be minimized.

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Authors' contributions

Conception or design of the work: Özgök A, Arslan ME

Data collection: Arslan ME

Data analysis and interpretation: Özgök A, Arslan ME

Drafting the article: Arslan ME

Critical revision of the article: Özgök A

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