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Anesthetic Considerations in Robotic-Assisted Gynecologic Surgery

Alan D. Kaye, MD, PhD,[*] Nalini Vadivelu, MD,[†] Nitin Ahuja, MBBS,[‡] Sukanya Mitra, MD,[‡] Dan Silasi, MD,[||] Richard D. Urman, MD[§]

[*]*Departments of Anesthesiology and Pharmacology, Louisiana State University Health Sciences Center, New Orleans, LA*
[†]*Department of Anesthesiology, Yale School of Medicine, New Haven, CT*
[‡]*Department of Anesthesiology, Chandigarh Government Medical College, Chandigarh, India*
[||]*Department of Obstetrics and Gynecology, Yale School of Medicine, New Haven, CT*
[§]*Department of Anesthesiology, Brigham and Women's Hospital, Boston, MA*

ABSTRACT

Background: Robotic-assisted surgery has evolved over the past 2 decades with constantly improving technology that assists surgeons in multiple subspecialty disciplines. The surgical requirements of lithotomy and steep Trendelenburg positions, along with the creation of a pneumoperitoneum and lack of direct access to the patient all present management challenges in gynecologic surgery. Patient positioning requirements can have significant physiologic effects and can result in many complications.

Methods: This review focuses on the anesthetic and surgical implications of robot-assisted technology in gynecologic surgery.

Conclusion: Good communication among team members and knowledge of the nuances of robotic surgery have the potential to improve patient outcomes, increase efficiency, and reduce complications.

Address correspondence to
Alan D. Kaye, MD, PhD
Professor and Chairman
Department of Anesthesiology
Louisiana State University School of Medicine
1542 Tulane Ave., Room 656
New Orleans, LA 70112
Tel: (504) 568-2319
Fax: (504) 568-2317
Email: akaye@lsuhsc.edu

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INTRODUCTION

Recent advancements in surgical procedures have led to greater emphasis on minimally invasive techniques with the goal of improving patient outcomes and satisfaction while decreasing surgical morbidity and mortality. Robotic-assisted surgery, the latest innovation in the field of minimally invasive surgeries, first came into medical practice in 1999.[1] The basic principle behind this technology is that the robot teleports the surgeon to the operating site and enables operation on the patient from an ergonomic console using 3-dimensional vision and autonomous control of wristed laparoscopic surgical instruments.[2,3] Advantages of robotic-assisted surgery include improved precision and enhanced accuracy of movement, both of which translate into potential benefits for patients.[4,5]

Laparoscopic surgery, introduced in the late 1980s, had certain limitations, such as loss of typical 3-dimensional vision, reduced surgeon coordination, and greatly limited touch.[1] Robotic technology overcame many of these obstacles as the technology improved over the years.[6] The da Vinci Surgical System mimics a human wrist and includes 3 distinct pieces: a console, a surgical cart with 4 arms (2 representing a surgeon's left and right arms, 1 arm to hold and position the endoscope, and an optional fourth arm to perform other tasks), and an optical 3-dimensional tower that provides stereoscopic vision and runs the software.[1]

The first robot-assisted surgical procedure was a laparoscopic cholecystectomy in 1997; one of the first gynecologic surgeries performed with the da Vinci system was a tubal reanastomosis.[7] Robotic-assisted techniques are being increasingly used for various gynecologic procedures, including total and supracervical hysterectomy, myomectomy, tubal reanastomosis, ovarian cystectomy, sacrocolpopexy, trachelectomy, lymph node dissection, and surgery for endometriosis and ectopic pregnancy.[8-10]

In recent years, the number of and indications for robotic-assisted gynecologic surgeries have increased. While a number of excellent surgical reviews are now available on the subject, few focus on anesthetic aspects and specific complications related to gynecologic surgery with robotic technology. The surgical requirements of the steep Trendelenburg position along with creation of a pneumoperitoneum present management challenges in gynecologic surgery. This review focuses, therefore, on anesthetic and surgical implications of robotic-assisted technology in gynecologic surgery.

ROBOTIC-ASSISTED SURGERIES

Robotic-assisted surgeries have gained popularity in gynecologic surgery because the robot can be manipulated through the natural orifices. Wrist-like movements of a robot permit the surgeon to perform with accuracy at the surgical site from a distance. The robotic technique is thus most suitable for operations in a closed and confined space such as the pelvis.[10]

Compared to conventional laparoscopy, robotic-assisted gynecologic surgeries help the surgeon perform complicated procedures with ease, such as securing uterine vessels and cardinal ligaments, performing an accurate colpotomy, and oversewing the vaginal cuff.[11] Several study groups have reported on the feasibility of complex endometriosis surgery with the da Vinci Surgical System.[10,12,13] Areas in which robotic surgeries seem to be making a mark are complex cases with severe adhesions, scarring, and difficult anatomical conditions where fertility preservation would be extremely difficult with conventional laparoscopy or laparotomy. In addition, recent reports by Tan et al,[6] Liu et al,[11] Weinberg et al,[14] Swan and Advincula,[15] Kalmar et al,[16] and Lowery et al[17] have shown that robotic surgeries are feasible and safe for patients with complicated gynecologic diseases compared to the conventional laparoscopic or open surgeries.

CENTRAL ISSUES FOR THE ANESTHESIOLOGIST

Critical issues for the anesthesiologist during robotic procedures include steep Trendelenburg position, the physiologic consequences of pneumoperitoneum and patient positioning, hypothermia, restricted access to the patient, venous gas embolism, and subcutaneous emphysema. Some of the physiologic changes and complications associated with robotic surgery are outlined in Tables 1 and 2.

Patient Positioning

Patient positioning is the most critical part of any robotic-assisted surgery. Without proper patient positioning and port placement, robotic-assisted procedures are tedious to perform and patient outcomes are compromised.[25] Once the surgery begins, the patient cannot be moved to any other position during the entire robotic part of the procedure, making the positioning of the patient even more challenging.

The steep Trendelenburg position provides the optimal exposure of the pelvis and the lower abdomen.[18] Placing the patients in this position for extended periods can lead to significant physiologic consequences. For example, the downward movement of the diaphragm by abdominal contents and pneumoperitoneum can decrease pulmonary compliance and functional residual capacity, cause pulmonary edema, and exacerbate ventilation/perfusion mismatch.[16,26,27] Additional effects on the cardiopulmonary system are discussed in the next section. These effects may further complicate clinical management of patients with underlying chronic lung disease or the morbidly obese. By pushing the trachea cephalad, Trendelenburg position can lead to displacement of the endotracheal tube by pushing it further in, resulting in mainstem intubation.[28]

Steep inclination of 25-45 degrees for a prolonged period can lead to upper airway and brain edema[1] and an increase in intracranial pressure and cerebral blood flow. To preserve cerebrovascular homeostasis, normocarbia should be maintained. Previous studies have also shown that the steep Trendelenburg position for long hours during gynecologic procedures has led to postoperative vision loss.[20] Also, facial engorgement and edema are quite substantial. These physiological changes led Molloy[23] to hypothesize that under anesthesia in steep Trendelenburg position, cerebrovascular and ophthalmic circulatory autoregulation do not prevent increases in intraocular pressure (IOP) and decreases in ocular perfusion pressure (OPP), which is mean arterial pressure (MAP) minus IOP. The Malloy study showed that even under anesthesia, cerebrovascular and ophthalmic circulatory autoregulation do not prevent complications such as increased IOP.[23]

Pneumoperitoneum

Pneumoperitoneum refers to the presence of air within the peritoneal cavity. Despite other options such as oxygen, helium, argon, and nitrous oxide, carbon dioxide (CO_2) remains the agent most commonly used for creating the pneumoperitoneum because of the problems associated with other gases, such as their combustible nature and the possibility of intravascular embolism on insufflation.

Table 1. Issues for the Anesthesiologist in Robotic-Assisted Gynecologic Surgery

Issues	Description	Anesthetic Implications	Prevention/Management
Patient Positioning	Steep Trendelenburg	Compromised hemodynamics	Adequate hydration, placement of central venous and arterial cannula
		Compromised oxygenation	Increase in inspired oxygen concentration
		Restricted intraoperative airway access	Proper fixing of endotracheal tube, field avoidance precautions
		Postoperative respiratory distress	Astute vigilance
		Nerve injury	Proper padding of pressure points, taping a foam egg crate mattress to the operating room table
		Occult blood loss	Monitoring blood volume replacement
		Corneal abrasion	Eye patch
Pneumo-peritoneum	CO_2 insufflation of peritoneum or thorax, often for prolonged periods	Increased peak and plateau airway pressures while decrease in the pulmonary compliance and vital capacity, leading to ventilation-perfusion mismatch	Monitoring, changing to pressure-control mode of ventilation if needed
		Atelectasis	Postoperative CPAP or BiPAP
		Gas embolism	Vigilance, discontinuation of N_2O, restricting intraabdominal pressure and CO_2 insufflation
		Hypotension	Fluids, vasopressors
Hypothermia	May develop because of exposure, long surgery, cold intravenous fluids, respiratory gases and CO_2 insufflation	Usual anesthetic implications	Temperature monitoring, warm fluids, warm humidified gases
Restricted Access	Restricted access to the patient once the bulky robot is draped and docked; limited access to the heart for direct defibrillation	Difficulty in emergency situations	Anticipation, rehearsal in undocking, proper precautions with tube and intravenous / arterial lines, use of transesophageal echocardiography, provision for external transthoracic defibrillation

BiPAP, bilevel positive airway pressure; CO_2, carbon dioxide; CPAP, continuous positive airway pressure; N_2O, nitrous oxide.

Intraperitoneal insufflation with CO_2 is performed in Trendelenburg position when the patient is positioned at an angle of 15-20 degrees. There is also a significant effect on respiratory mechanics. Lung compliance can decrease by more than 50%, and mean pulmonary arterial pressure and pulmonary capillary wedge pressure also decrease.[29] In addition, there is an increase in peak inspiratory pressure, plateau pressure, and end-tidal CO_2 tension.[19] The CO_2 insufflation can result in increased postoperative complications in patients with underlying lung disease. For example, patients with conditions such as chronic obstructive pulmonary disease are less efficient in eliminating excessive

Table 2. Complications and Their Anesthetic Implications in Robotic-Assisted Gynecologic Surgeries

Study	Complication Discussed	Anesthetic Implication	Solution
Klauschie et al, 2010[18]	Patient in steep Trendelenburg sliding during surgery	Neuropathic injuries	Use of antiskid material for heavy patients and patients undergoing long procedures
Suh et al, 2010[19]	Conditions such as pneumothorax, pneumomediastinum, and pneumopericardium because of the exaggerated angle of steep Trendelenburg	Subcutaneous emphysema, hypercarbia, respiratory acidosis, atelectasis	Hyperventilation, pressure-controlled and volume-controlled ventilation, use of PEEP
Awad et al, 2009[20]	Increased CVP and IOP	Increased arterial CO_2 leading to choroidal vasodilation	Positive pressure ventilation, hemodynamic maintenance, ventilation strategy, and fluid management
Zorko et al, 2011[21]	Hemodynamic complications because of prolonged steep Trendelenburg	Significant increase in cardiac output and mean arterial pressure; a nonsignificant decrease in heart rate	Awareness required of anesthesia team regarding significant increase in cardiac output and mean arterial pressure in steep Trendelenburg position
Gupta et al, 2012[22]	Long surgery duration	Hypothermia	Active warming procedures
Molloy, 2011[23]	Increased IOP	OPP falls below IOP, leading to a state of hypoperfusion with obstruction of blood flow	Operating table brought to the supine position halfway through the procedure
Kalmar et al, 2010[16]	Altered cardiovascular, cerebrovascular, and respiratory homeostasis	Choroidal vasodilation and increased IOP due to CO_2 pneumoperitoneum, increased intracranial pressure and increased end-tidal CO_2 tension	Maintenance of a physiological arterial CO_2 tension
Pandey et al, 2012[24]	Hemiparesis	Cerebral air embolism	Reconsideration of the duration of the steep Trendelenburg position and pneumoperitoneum pressures

CO_2, carbon dioxide; CVP, central venous pressure; IOP, intraocular pressure; OPP, ocular perfusion pressure; PEEP, positive end-expiratory pressure.

CO_2 even with increased minute volume of ventilation. This deficiency can lead to postoperative respiratory hypercarbia and acidosis, requiring prolonged mechanical ventilation.[30,31]

The combination of the steep Trendelenburg position with pneumoperitoneum influences cardiopulmonary physiology in many ways.[32] Pneumoperitoneum and a 45-degree Trendelenburg position have been shown to cause 2- to 3-fold increases in left ventricular filling pressures,[33] and cardiac output may decrease.[34] Systemic vascular resistance and MAP also increase, whereas renal, splanchnic, and portal flows decrease. Activation of the renin-angiotensin system increases the levels of vasopressin.

PERIOPERATIVE COMPLICATIONS

The mere availability of robotic surgical capability cannot by itself guarantee a successful surgical program. Teamwork is essential for successful patient outcomes. The anesthesiologist must be ready to deal with the consequences of the steep learning curve, stressed surgeons, and the long duration of most procedures. Also, the anesthesiologist must be prepared to handle new challenges associated with proper patient selection and screening, as well as intraoperative care challenges.[22,35] Invasion of the anesthetic workspace with the robotic system is almost unavoidable, and anesthesiologists must be aware that the size of the robot might interfere with their ability to quickly access the patient.[36] Proper positioning of the patient is a necessary first step for robotic-assisted laparoscopic procedures. Without proper patient positioning and port placement, robotic-assisted procedures are tedious to perform and patient outcomes are compromised.[25] The most common complications and their anesthetic implications are summarized in Table 2.

Patient Positioning

Obtaining the proper patient position is a dynamic process that requires the supervision of the surgeon. Not only should the patient be protected from injuries, but the optimal position must also allow for safe docking of the robot as well as for access of the bedside surgeon to the surgical assistant ports.[23] Once the procedure begins, the anesthesiologist and the surgeon are limited in making any changes to or improving the positioning of the patient. Consequently, the anesthesiologist must carefully arrange intravenous access and arterial lines (if required) prior to positioning because access will be limited once the robotic portion of the procedure starts. Bilateral peripheral intravenous access is generally advised.

During the steep Trendelenburg position in gynecologic surgeries, shifting the patient's trunk often leads to suboptimal positioning of the extremities, increasing the risk of nerve injury from stretch and compression. Lower extremity acute compartment syndrome requiring fasciotomy and rhabdomyolysis resulting in renal failure as a result of prolonged intraoperative lithotomy position have been reported.[37,38]

Groups around the world have suggested methods to prevent patient shifting during the steep Trendelenburg position, including braces, leg suspension, and iliac supports. However, all of these methods can potentially result in nerve injury,[39-42] and the shoulder braces and straps used to prevent the patient from shifting can cause neuropathic injury.[32] During robotic-assisted gynecologic surgeries, the trocars and instruments are fixed, so the prevention of patient sliding becomes all the more important. The risk of stretching and tearing of the incisions, which may increase the risk of an incisional hernia, is a concern. Klauschie et al[18] demonstrated for the first time the use of an antiskid foam material for patient positioning. Although they observed small shifts in patient positioning, no clinical neurologic injuries were noted.

Most vulnerable to the head-down extreme position are the cardiac, respiratory, and central nervous systems.[10] Because any intraoperative movement can be catastrophic, muscle relaxation is critical for success. Other complications include unrecognized surgical injury, occult blood loss, and risk of hypothermia.[1,43]

Cardiopulmonary Complications

As discussed previously, the combination of pneumoperitoneum and steep Trendelenburg causes pulmonary problems such as atelectasis and ventilation-perfusion mismatch.[1] A decrease in the pulmonary compliance and functional residual capacity is observed, but the peak airway pressures increase. White and Freire[44] demonstrated how subcutaneous emphysema occurs frequently with the steep Trendelenburg position and may contribute significantly to the total amount of CO_2 absorbed in addition to the absorption of peritoneal CO_2 insufflation. Ideally, hyperventilation is the solution to the hypercarbia and respiratory acidosis, but in the steep Trendelenburg position, hyperventilation is limited during robotic surgery by a higher ventilator-inspired pressure. Plus, the abdominal CO_2 insufflation also limits diaphragmatic excursion.[27] In this setting, Oğurlu et al[45] observed lower peak airway pressure and plateau pressure with higher lung compliance with the use of pressure-controlled ventilation. This use of pressure-controlled ventilation—allowing a larger tidal volume for the same inspired pressure—might be particularly useful for patients for whom it is difficult to achieve adequate oxygenation.[46]

Positive end-expiratory pressure (PEEP) can help decrease atelectasis. PEEP improves intraoperative oxygenation and lung mechanics, impedes the venous blood return from the lower extremities, and decreases cardiac output, but these effects are likely to be negated by the steep Trendelenburg position. Limiting the amount of CO_2 insufflation causing increased venous congestion in the upper extremity can help prevent facial and airway edema.[47]

Many patients with endometrial cancer are obese and have less efficient ventilation during pneumoperitoneum.[48] These patients present with further challenges in airway management, and they may be at higher risk of coronary artery disease, pulmonary dysfunction, and diabetes.[17] In general, the hindrance to normal diaphragmatic excursion is substantial when these patients are placed in the steep Trendelenburg position.[49]

With the creation of pneumoperitoneum, immediate gas embolism may occur, and in very rare cases it can cause severe cardiovascular failure, reduction of pulmonary blood flow, and death. The clinical manifestations generally include a sudden increase followed by a rapid drop in end-tidal CO_2, tachycardia, hypotension, diminished breath sounds in a specific lung field on auscultation, cyanosis, and a classic cardiac murmur (mill-wheel murmur) associated with gas embolization. The mechanism is perceived to be infiltration of insufflated CO_2 into venous/lymphatic channels with pulmonary migration, presumed to occur from rapid insufflation of gas directly into the bloodstream.[36] Certain measures to avoid and to treat this complication include rapid removal of pneumoperitoneum, hyperventilation with oxygen, placing the patient in the left lateral decubitus and Trendelenburg positions, cardiopulmonary resuscitation, and potentially aspirating the embolus via a central venous catheter or needle insertion directly into the right ventricle via a substernal approach aimed toward the left shoulder with subsequent therapeutic aspiration of gas.[36,48] During the procedure, CO_2 should be used for insufflation because of its high diffusion coefficient to minimize the risk of gas emboli.[21] The anesthesiologist needs to use extreme caution and measure CO_2 levels at the end of exhalation so he/she can adjust the ventilator to remove excess CO_2 and help prevent hypercarbia and acidosis.

Cardiac arrhythmias and vagal reactions secondary to peritoneal distention during insufflation or viscus manipulation and diminished cardiac preload secondary to caval compression can contribute to a catastrophic outcome and asystolic cardiac arrest. Hypoxia or hypercapnia can result in cardiac arrhythmias. The combination of Trendelenburg positioning and elevated intraabdominal compartment pressures predispose a patient to aspiration, potentially resulting in hypoxia and possibly hypercapnia. Theoretically, hypercapnia can also occur from CO_2 absorption during pneumoperitoneum.

Other Complications

Another major anesthetic consideration during robotic-assisted surgery for endometrial cancers is the prolonged anesthesia that accentuates the problems highlighted above by placing a longer challenge on the patient's cardiorespiratory capacity.[50] Prolonged anesthesia is a key area of concern with all robotic-assisted gynecologic procedures. Because many patients undergoing gynecologic surgery are discharged home the same day, adequate pain control and postoperative nausea and vomiting (PONV) are significant concerns. Multimodal approaches to pain management and appropriate PONV prophylaxis have been shown to decrease length of stay and improve patient satisfaction.[51,52]

TEAMWORK AND COMMUNICATION

Given all of the technological aspects of robotic surgery and the potential physiological consequences and risk of morbidity and mortality specific to gynecologic surgeries, the use of robotic surgery simulation programs may afford distinct advantages when preparing personnel for success in the operating room. Simulation has the potential to improve outcomes and reduce complications while enhancing teamwork.[53] In addition, good communication among all members of the team, including surgeons, anesthesiologists, and nurses is the key to a safe, effective, and efficient environment. The addition of audio speakers to transmit the surgeon's voice can also improve communication among team members.[22]

CONCLUSION

In 2 short decades, robotic surgery has grown into its own subspecialty. As with other procedures, gynecologic robotic-assisted procedures are associated with potentially serious complications as a result of steep Trendelenburg positioning, creation of pneumoperitoneum, and difficult access to the patient. Common complications include positioning injuries, upper body edema, cardiopulmonary compromise, subcutaneous emphysema, and hypothermia. In a review of the literature, the American Association of Gynecology reported an incidence of 1 in 2,500 cases of asystole and arrest during laparoscopy, reflecting the potential for catastrophic morbidity and mortality.[54,55]

Teamwork and communication among surgeons, nurses, and anesthesiologists are essential to minimize complications and improve surgical conditions and patient outcomes.

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