Cardiopulmonary Collapse in the Wake of Robotic Surgery

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Since the Food and Drug Administration approved the da Vinci Surgical System in 2000, robotic surgery is becoming increasingly popular in the operating room. Despite its popularity and proposed benefits, robotic surgeries encompass many complications that are often confounded by the patient's physiology and comorbidities. This article illustrates a case study of a patient who underwent a da Vinci ureterectomy. The case study will highlight the implications and complications that may arise with pneumoperitoneum and steep Trendelenburg positioning, and an overview of the current literature in robotic surgery will be presented.

Keywords: Cardiopulmonary arrest, CO2 insufflation, pneumoperitoneum, robotic surgery, steep Trendelenburg position.

The first description of robots dates back to 1023–957 BC. Since that time, numerous historical records of robotic development can be found across cultures. Despite its early presence in human history, the use of robots specifically for surgery only began at the turn of the 20th century.[1] In 2000, the da Vinci Surgical System, designed by Intuitive Surgical, Inc., became the first Food and Drug Administration–approved surgical robot for both adult and pediatric use in general laparoscopic surgery, noncardiovascular thoracoscopic surgery and thoracoscopically assisted cardiotomy.[2] With reported benefits of shorter hospital stays, less surgical blood loss, faster patient recovery, and less postoperative pain, the use of the da Vinci Surgical System has gained popularity since its debut. An estimated total of 205,000 robotic cases were performed in 2009, and approximately 1.5 million cases were performed worldwide in 2013.[1,3,4] Despite its popularity and proposed benefits, robotic surgeries encompass many complications that are often confounded by the patient's body habitus and comorbidities. This article presents a case study of a patient undergoing a robotic ureterectomy. The case study highlights the anesthetic implications and complications of robotic surgery and discusses the current literature in anesthetic management. As more surgeons and institutions adopt the da Vinci Surgical System, anesthesia providers must modify their anesthetic management to account for the effects of this new technology.

Case Summary

A 61-year-old, 183-cm tall and 97-kg male was scheduled for a da Vinci ureterectomy. The patient's medical report revealed an extensive renal, cardiac and pulmonary history, which included renal cancer; end stage renal disease requiring hemodialysis; diabetes; hyperlipidemia; hypertension; coronary artery disease with multiple stent placements; a coronary artery bypass graft in 2005; chronic obstructive pulmonary disease; bronchitis; and obstructive sleep apnea. While on the kidney transplant list, he underwent bilateral nephrectomies in 2012 without surgical or anesthetic complications. A recent routine follow-up with his physician indicated that the cancer had metastasized to his ureter, and he was consequently scheduled for a robotic ureterectomy.

The patient was designated a physical status 3 (ASA 3). His current medications included metoprolol, atorvastatin, cinacalcet, sevelamer, fexofenadine, erythropoietin, fluticasone/salmeterol, tiotropium, and albuterol. The last reported dose of metoprolol was taken the night prior to surgery. A review of his laboratory report showed all postdialysis laboratory values within the patient's baseline. The results of the tests were as follows: potassium 3.5 mEq/L, calcium 8.0 mg/dL, BUN 55 mg/dL, creatinine 5.7 mg/dL, hemoglobin 10.3 g/dL, and hematocrit 31.2%. A recent cardiac catheterization revealed an ejection fraction of 38%. With the arteriovenous fistula on the left arm, a large-bore peripheral IV catheter and an arterial line were placed in the patient's right arm prior to surgery—in anticipation of potential perioperative hemodynamic instability. A Mallampati score of 3 was identified upon evaluation of the airway. Although no signs or symptoms of acute respiratory distress were present, mild wheezing could be auscultated throughout bilateral lung fields. The patient reported a 60-pack per year smoking history, with his last cigarette smoked just 1 day prior to this admission for surgery. A nicotine patch was administered on the patient's upper arm, and after receiving a dose of fluticasone/salmeterol, tiotropium, albuterol and midazolam 1 mg IV, the patient was transported to the operating room.

Following the transfer of the patient from the stretcher to the OR table, standard monitors were placed. After achieving adequate preoxygenation, the patient was induced with fentanyl 100 µg IV, lidocaine 2% 100 mg IV, etomidate 20 mg IV, and cisatracurium 10 mg IV, and intubated with a 7.5 mm endotracheal tube with a Glidescope™ (Verathon Inc., Bothell, WA). Sevoflurane was initiated and titrated to effect. A Bispectral Index Monitor (Philips, Norwood, MA), oral gastric tube, and upper body convective warmer were employed. With the trocars and the da Vinci Surgical System in place, a peripheral nerve stimulator guided neuromuscular blockade, which was maintained with intermittent doses of cisatracurium 2 mg IV. The surgery lasted 3 hours without incident, with steep Trendelenburg positioning at approximately 45 degrees and insufflation pressures between 12–15 mm Hg. Volume control mechanical ventilation was utilized during the surgery, with ventilator settings adjusted to minimize peak pressures and end-tidal CO_2. Given the patient's pulmonary and renal history, <500 mL of fluids were administered per the surgeon's request. Neostigmine 4 mg IV and glycopyrrolate 0.6 mg IV were administered at the end of the case, and signs of neuromuscular function recovery—including adequate minute ventilation, sustained head lift, and purposeful movements—were observed prior to extubation.

Upon transfer from the OR table to the stretcher, the patient became apneic, unresponsive, and pulseless—the OR team initiated resuscitation protocols within seconds of the arrest. Mask ventilation and chest compressions were performed as additional operating room, anesthesia, and surgical staff arrived to help. The patient was reintubated with an endotracheal tube using the Glidescope™ and a total of 2 doses of epinephrine 1 mg IV were administered during cardiopulmonary resuscitation. After approximately 10 minutes from time of event onset, his heart rate and blood pressure returned to baseline, but he still required assisted ventilation. Upon stabilization, the patient was transferred to the postanesthesia care unit with the endotracheal tube in place, and a chest X-ray confirmed the diagnosis of congestive heart failure.

Discussion

The event illustrated that the anesthetic implications associated with robotic surgery can be inextricably confounded by the patient's comorbidities and physiology. Although the true trigger that initiated the event is at best speculative, a focus on the potential cardiovascular and pulmonary effects of robotic surgery will be presented.

To enhance the visualization and access to the surgical site, pneumoperitoneum and steep Trendelenburg positioning are commonly implemented with robotic surgery. Depending on the surgeon's experience and the type of surgery, it is not unusual for patients to sustain these physiologic conditions for 3–6 hours. High insufflation pressures >18 mm Hg can decrease venous return and cardiac output, while Trendelenburg positioning and moderate insufflation pressures can increase venous return and cardiac output in healthy individuals. Hypercarbia as a result of CO_2 absorption stimulates the sympathetic nervous system to release catecholamines, which in turn may increase the mean arterial pressure and cardiac output.[5] In this case study, it is possible that the sympathetic and physiologic effects of steep Trendelenburg and moderate insufflation masked this patient's true hemodynamic status intraoperatively. The oxygen demand imposed on the body with the increase in venous return and systemic vascular resistance most likely increased the patient's myocardial workload during the 3-hour surgery. With the abdomen deflated and the bed leveled on emergence, an abrupt decrease in preload—resulting in a drop in cardiac output—may have set the stage for the postoperative event. The triad of a sustained increase in myocardial oxygen demand, low preoperative ejection fraction, and abrupt fluid shift with deflation and leveling may have led to the cardiopulmonary arrest.

Similar to laparoscopic procedures, robotic surgeries entail CO_2 insufflation into the peritoneum. The elevated intraabdominal insufflation pressure increases peak inspiratory pressure, decreasing both functional residual capacity and lung compliance. The consequences of the physiological effects include ventilation/perfusion mismatch, pulmonary shunting, and increased risk of hypoxemia and atelectasis. Pressurized CO_2 increases the diffusion and absorption of the gas into the body's system, resulting in respiratory acidosis. Combined with the patient's preoperative COPD, obstructive sleep apnea, and smoking history, the effects of the pneumoperitoneum on the patient's pulmonary physiology may have contributed to the arrest. With the EKG leads and blood pressure cuff detached during patient transfer to stretcher, apnea and change of mental status were the first recognized signs of the collapse. Although it is possible that a cardiovascular and respiratory collapse occurred simultaneously, it remains undetermined as to which system triggered the event. Nevertheless, the patient in this case study had significant comorbidities that placed him at high risk for developing perioperative complications. Although only 2 systems were discussed in this case, the anesthetic implications and complications of robotic surgery extend to other body systems (Table). There are reports of complications such as stroke, renal failure, fistula formations, eviscerations, and ileus.[6] Similar to any prolonged extreme positioning during surgery, there are risks of nerve injuries, compression injuries, and increased intraocular pressure that require thoughtful consideration.[5]

With our increasingly complex patient population, it is worth reviewing the literature to evaluate the current risks and benefits of robotic surgery. In a prospective multi-institutional analysis of databases, robotic surgery complication rates increased with renal tumor complex-

System	Physiologic change	Effect
Cardiovascular	Pneumoperitoneum -hypercarbia	-SNS stimulation -Catecholamine release -Tachycardia -Increase MAP -Increase SVR
	Pneumoperitoneum - CO_2 insufflation (moderate pressure)	-Increase venous return -Increase CO -May present elevated or unchanged -VAGAL stimulation -Bradycardia -Hypotension
	Pneumoperitoneum - CO_2 insufflation (high pressure: >18 mm Hg)	-Decrease venous return -Decrease CO VAGAL stimulation -Bradycardia -Hypotension
	Steep Trendelenburg	-Increase venous return -Increase CO
Respiratory	Pneumoperitoneum - CO_2 insufflation Steep Trendelenburg	-Increase peak inspiratory pressure -Decrease FRC, total lung volume -Decrease lung compliance -V/Q mismatch -Pulmonary shunting -Hypoxemia -Respiratory acidosis
Neurology	Pneumoperitoneum - CO_2 insufflation Steep Trendelenburg	-Increase CO_2 tension -Increase cerebral blood flow -Increase ICP -Increase intraocular pressure
Renal	Pneumoperitoneum	-Increase intraabdominal pressure -Decrease renal perfusion
Gastrointestinal	Pneumoperitoneum Steep Trendelenburg	-Increase intraabdominal pressure -Aspiration risk

Table. Physiological Effects of Pneumoperitoneum and Steep Trendelenburg Positioning
Abbreviations: SNS, sympathetic nervous system; MAP, mean arterial pressure; SVR, systemic vascular resistance; CO, cardiac output; ICP, intracranial pressure; FRC, functional residual capacity; V/Q, ventilation/perfusion.

ity.[7] Of the complications noted in the study, hemorrhage was the most common. Specific to the respiratory system, complications—such as pulmonary edema, subcutaneous emphysema, pneumonia, and respiratory insufficiency that require mechanical ventilation—were cited. Relative to the cardiovascular system, there were cases of arrhythmias, hemodynamic instability, and myocardial infarction.[7] Further literature review provided mixed findings. In a study that compared robotic prostatectomy to the traditional laparoscopic and open approach, the laparoscopic and robotic approach had significantly shorter length of stay with less surgical blood loss and transfusions. Overall, the lowest complication rates were seen in the robotic group.[7] Despite the different outcomes presented in the literature, a common limitation in the robotic studies is the lack of controls. Although the da Vinci's technology has improved the visualization and precision of surgery, there are many factors—such as surgeon experience, team training, and patient comorbidities—that make conclusions controversial regarding the superiority of robotic approaches over conventional approaches.[7,8] There is a great need for a large, multi-institutional, prospective randomized clinical trial comparing the outcomes between robotic surgery and current traditional approaches to validate its safety and efficacy.[6-8] Many randomized controlled trial studies are still in the early pilot stages, and the literature detailing anesthetic management during robotic surgery is largely anecdotal.

In light of this patient event, it might be beneficial to explore preventive techniques, such as alternative positioning, a slow Trendelenburg taper with emergence, or the use of noninvasive fluid monitors. This case highlights an important reminder that, despite the advancements of technology and patient monitors, the anesthetist's vigilance remains at the forefront of safe practice. As the research and case reports in the literature have revealed, robotic surgery can act either synergistically or antagonistically with the patient's baseline condition. As the anesthetic provider, there is a need to be cognizant of the implications and the potential complications of robotic surgery. As science develops more advanced techniques and technologies in caring for patients, we can expect to see more patients presenting for surgery with increasingly complex comorbidities and physiologies. Our decisions influence outcome, and it is paramount as providers to be aware of the current literature in order to provide the safest, most evidence-based anesthetic care to our patients.

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