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Review Article

Anesthetic considerations for robotic prostatectomy: a review of the literature☆

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Abstract Since the first robotic prostatectomy in 2000, the number of prostatectomies performed using robot-assisted laparoscopy has been increasing. As of 2009, 90,000 robotic radical prostatectomies were performed worldwide, and 80% of all radical prostatectomies performed in the United States were performed robotically. Robotic prostatectomy is becoming more common globally because of the many advantages offered to patients, primarily due to the minimally invasive nature of the procedure. Several new perioperative concerns and challenges for anesthesiologists and are described.

1. Introduction

Prostate cancer is the most common non-skin cancer among American men of all races, and it continues to be the second leading cause of cancer-related death in men. The first reported radical prostatectomy was performed by Hugh Hampton Young in 1904 via a perineal approach. The retropubic approach was first performed by Terrence Millen in 1947 [1]. Patrick Walsh's revolutionary contributions in defining the anatomy of the prostate and its surrounding structures improved the surgical approach [1]. With the introduction of prostate-specific antigen testing, practitioners may detect prostate cancer before physically appreciable signs and symptoms emerge, allowing earlier intervention in the setting of localized disease [2].

Within this past decade, the introduction of the da Vinci® Surgical System (Intuitive Surgical, Sunnydale, CA, USA) has transformed the field of robotic surgery across the country and solved some of the limitations of traditional

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laparoscopic urology. In spite of the remarkable success with regard to the increase in the number of cases being performed every year [3], the debate about the use of the da Vinci Surgical System for robotic prostatectomy remains ongoing. The Swedish healthcare context performed the first head-to-head, multicenter, longterm prospective clinical trial from 2008 through October 2011. This trial aimed to compare the two surgical techniques with respect to short and long-term function and oncologic outcome, cost-effectiveness, and quality of life, providing new knowledge to support further decision and treatment strategy for prostate cancer [4].

Regardless of the outcome of the robotic prostatectomy study in Sweden, we believe that robotic prostatectomy is rapidly becoming a part of the standard surgical repertoire for the treatment of prostate cancer. Therefore, anesthesiologists need to be fully aware of, and prepared to handle, the challenges generated by this new technology, and manage the associated complications.

2. Perioperative concerns

Although the average age of men undergoing prostatectomy has decreased over the last few decades due to earlier detection, prostate cancer still remains a disease common to older men. Thus, the typical comorbidities associated with this demographic must be considered during the initial patient assessment for robotic prostatectomy.

Nevertheless, given the natural history of prostate cancer, typified by long latency and the availability of nonsurgical and potentially curative therapy in the form of radiation, prostatectomy is not routinely performed in those of extreme age or in patients having comorbidities that confer a life expectancy of less than 10 years.

Experienced surgeons average approximately two to three hours to complete robotic prostatectomy. There is a steep learning curve for the procedure, and a surgeon's initial surgeries often require 8 to 10 hours to complete, consequently placing the patient in a position that is not physiologic for an extended amount of time [5]. Even with experienced surgeons in a high-volume center, a learning curve persists beyond the first 200 cases [6,7], requiring anesthesiologists to tailor their anesthetic patient management accordingly.

For the surgical procedure, the patient is first placed in the lithotomy position, pneumoperitoneum is created, and then the patient is changed to the steep Trendelenburg position. This positioning allows for an intra-abdominal work space as well as retraction of the bowel from the surgical field by way of gravity. The combination of lithotomy position, abdominal insufflation pressure, then steep Trendelenburg positioning generates several physiological effects, including changes in hemodynamic, pulmonary, renal, ocular, and other systems.

2.1. Cardiovascular considerations

Determination of a patient's cardiac risk may be made during the history, physical examination, and electrocardiogram. The nature of intermediate-risk surgery (ie, robotic prostatectomy), history of ischemic heart disease, congestive heart failure, cerebral vascular disease, renal dysfunction, and preoperative insulin treatment all increase the risk of cardiac complications [2]. Thorough preoperative cardiac assessment guides appropriate interventions, decreases perioperative complications, and lessens long-term mortality. Current American Heart Association/American College of Cardiology (AHA/ACC) guidelines for the management of patients in the preoperative setting recommend cancellation or delay of nonemergent cases in patients with the following conditions: angina, recent myocardial infarction, decompensated heart failure, significant arrhythmias, and severe valvular disease [8].

To address the need for transition of anticoagulation in patients with drug-eluting stents who require robotic surgical procedures, two case reports have documented that death may occur even a few years after stent placement with robotic prostatectomy surgery. These two cases raise questions about the need to transition for anticoagulation in patients with drug-eluting stents who require robotic surgical procedures similar to other noncardiac surgeries. These case reports also detail how both patients had the procedure a few years after the percutaneous coronary intervention (PCI) and still developed fatality, even after presumed reendothelialization [9,10]. These two cases reflect the difficulty faced by all anesthesiologists on a daily basis for noncardiac procedures, such as robotic prostatectomy after PCI. Adding to that difficulty, there is national controversy surrounding the patient's predisposition to stent thrombosis even while receiving antiplatelet drugs. In 2010, a debate erupted among the U.S. Food and Drug Administration (FDA), AHA, and ACC concerning the need and value of genetic testing for CYP2C19. The determination as to which subgroup has a higher risk of cardiovascular complication, including death, remains unresolved, and reflects the complexity of cardiovascular biology in this field. It is hoped that more research will be done to bring a definitive solution to this important issue [11].

2.2. Intracranial concerns

To perform the surgery, the patient must be placed in a position that is not physiologic, in some cases for an extended period of time. Steep Trendelenburg positioning and insufflation of CO_2 to generate pneumoperitoneum increase intracranial pressures (ICPs) when used alone or in combination [12–14]. Park et al showed an increase in regional cerebral oxygenation due to increased partial pressure of CO_2 ($PaCO_2$) during use of the da Vinci Surgical System in patients without intracranial pathology [15]. Using second-generation near infrared spectroscopy, Kalmar et al recently reported maintenance of cerebral perfusion pressure (CPP) above the lower threshold of autoregulation of cerebral circulation due to a simultaneous increase in mean arterial pressure (MAP) and central venous pressure (CVP) in robotic prostatectomies [16]. However, the perioperative team should be cautious when placing patients with increased ICPs in the steep Trendelenburg position and inducing pneumoperitoneum for an extended period of time. For patients with intracranial pathology who have a functioning ventriculoperitoneal (VP) shunt, any increase in ICP leads to a pressure differential between the ventricular and peritoneal compartments and an increased flow rate through the shunt. Thus, it is important to ensure the functionality of the shunt by either checking free cerebrospinal fluid drainage from the catheter in a distal extremity at the beginning, middle, and end of a procedure, or by transcranial Doppler at the initiation and conclusion of any laparoscopic procedure [17]. Furthermore, a neurosurgery consult is recommended to discuss the appropriate abdominal insufflation pressures, length of procedure, and monitoring for any patient with VP shunt or increased ICPs before undergoing the procedure.

2.3. Obesity

In general, urologic cases that involve robotic technique and obese patients with a body mass index greater than 30 kg/m^2 present additional challenges to the anesthesiologist and surgeon. In a study by Wiltz et al, obese patients experienced increased open conversion rates (2.3%) compared with nonobese patients (0.9%), with over 80% of these open conversion cases due to higher expiratory airway pressures [18]. If the operative team is confronted with markedly increased airway pressures after placing a morbidly obese patient in the lithotomy and steep Trendelenburg positions, they have to make a decision to abort or convert to an open procedure. Ideally, this situation is discussed with the patient before induction of anesthesia so as to determine preference for open prostatectomy versus alternative therapy, such as radiation-based therapies, in the event that robotic prostatectomy is not achievable.

2.4. Renal function

Cho et al recently found a transient increase in serum creatinine and estimated glomerular filtration rate (GFR) on postoperative days (PODs) 1 and 3 after robotic prostatectomy, partially due to the effects of pneumoperitoneum on urinary excretion, creatinine clearance, GFR, and renal blood flow (RBF). The group used the calcium channel blocker nifedipine (0.5 ug/kg/min) and showed a decrease in transient renal dysfunction by preferentially vasodilating renal arterioles in patients with normal renal function [19]. In a prospective, randomized study of men and women undergoing laparoscopic colorectal surgery, Perez et al found that dopamine at a renal dose of 2 ug/kg/min helped to prevent kidney dysfunction caused by the increased intra-abdominal pressure (IAP) associated with pneumoperitoneum [20]. The change in cardiac output due to pneumoperitoneum varies depending on the introduction of hypercarbia and volume status, which invariably affects RBF to the kidneys.

2.5. Bowel preparation

Although the bowel is not entered in prostatectomy, surgeons include a standard bowel preparation in patients undergoing prostatectomy due to the reported 0.2% to 8% incidence of rectal injury [21]. The preparation decompresses the bowel, creating additional work space within the abdominal cavity, and minimizing fecal contamination of the wound. This situation allows for selective rectal repair without diverting colostomy when rectal injuries are small. It should be noted that with the two most common bowel preparation agents (polyethylene glycol and sodium phosphate), there is similar efficacy and tolerability. However, after preparation with sodium phosphate, there is a small risk of hyperphosphatemia and phosphate nephropathy due to nephrocalcinosis, resulting in kidney injury [22–24].

2.6. Intraocular concerns

A recent ASA 2011 abstract reported three cases of permanent vision loss with robotic prostatectomy. These cases were drawn from a database that included cases from 2006 to 2010, with an anesthetic duration of 7.9 to 9.9 hours and onset of symptoms within 24 hours postoperatively. The range of Trendelenburg positioning for 5 of 6 prostatectomy cases was estimated between 10 and 30 degrees (n = 4) or "steep" Trendelenburg (n = 1) [25]. Another report, by a neuroophthalmology group, presented two more cases that showed a risk of vision defects and loss after robotic prostatectomy in healthy patients [26]. These two cases included significant blood loss, contrasting with the other cases in the ASA database that did not include significant blood loss. Our group became aware of the case of a bilateral retinal tear after robotic prostatectomy that was diagnosed 10 days after surgery (personal communication). The exact mechanisms for this loss of vision remain unclear and require further study. Our group showed that during robot-assisted laparoscopic prostatectomy (RALP) surgery, the intraocular pressure (IOP) of a patient in the steep Trendelenburg position increased by a statistically significant 13.3 mmHg over baseline over 60 minutes, then increased to the level of a glaucoma patient who has ceased medication [27]. The effects of both the increased IOP and orbital pressure on nerve fiber layers during prolonged steep Trendelenburg positioning are unknown. There are no strategies for the management of patients with an increased baseline of IOP or whether patients undergoing prolonged Trendelenburg positioning require vision screening or perioperative medication to decrease the IOP. One prospective study of coronary artery bypass graft patients showed that of those who had some degree of vision loss, 50% had a preexisting condition noted on presurgical examination [28].

It is reasonable to explain to the patient the minimal risk of postoperative orbital pain and periorbital edema, which are transient. Early on, our experiences at our institution showed a high incidence of transient postoperative pain in both eyes, triggering an ophthalmology consult. The cause of this pain is unknown, although it may be related to scleral or cornea edema and not to the way the eyes are taped. In any patient with an increased baseline of IOP or intraocular pathology, an ophthalmology consultation is warranted to examine the eyes and assess the potential risk of the procedure.

3. Intraoperative concerns

Use of the da Vinci Surgical System requires additional precautions not normally needed for other laparoscopic procedures. First, the robot is rigidly fixed with regard to its trocar insertion sites. Any patient movement stresses these port sites and places at risk delicate vascular and visceral structures. While the robotic system provides a stable basis for multidimensional tissue manipulation, it also serves as a serious impediment in the event that a patient requires Advanced Cardiac Life Support (ACLS) protocol in the operating room (OR). A recent consensus document outlined the need for clear communication among the perioperative team concerning an emergency plan that allows all of the trocars to be removed from the patient and the robot pulled back in less than one minute [29]. In addition, consideration should be given to placing two intravenous (IV) catheters in the event of accidental removal during disengagement of the robot from the patient, particularly due to the limited access to the patient's arms during the procedure.

3.1. Airway management

Checking the position of the endotracheal tube (ETT) before and after insufflation to create pneumoperitoneum and placing the patient in steep Trendelenburg position is recommended. This is because of the possibility of ETT displacement into the bronchus due to distance changes between the vocal cords/ETT tip and the ETT tip/carina [30]. The Fourth National Audit Project (NAP4) performed a prospective study of all major airway events during anesthesia in the intensive care unit and the emergency department that occurred throughout the 4 countries of the United Kingdom for one year [31]. The study examined airway complications related to robotic prostatectomy secondary to the steep Trendelenburg position. Three cases of airway problems after steep Trendelenburg positioning were reported, and one of the three cases was described in detail. During this case, a middle-aged patient underwent a 6-hour laparoscopic operation in extreme Trendelenburg position. At induction, the laryngoscopic view was grade 3 and a bougie was used for intubation. After extubation, the patient developed stridor and upper airway obstruction, which improved after insertion of a supraglottic airway device, but recurred on its removal. Fiberoptic endoscopy through the supraglottic airway device showed laryngeal edema, and the patient was intubated over an Aintree intubation catheter (Cook Medical, Inc., Bloomington, IN, USA) that passed through the supraglottic airway device over a fiberscope [32]. These reported cases from the NAP4 study reflect the need for careful management of the airway during extubation, including delaying extubation until the airway edema subsides, especially in cases of difficult intubation and prolonged steep Trendelenburg positioning.

3.2. Patient positioning

The potential for long operative times at the beginning of the learning curve for robotic prostatectomy necessitates ideal patient positioning to prevent neuropathies. Risk factors for injury include diabetes, thin body habitus, and improper placement or inadequate padding of the robot's immobile arms on the patient's lower extremities [33]. Multiple nerves in the upper and lower extremity are susceptible to injury during robotic prostatectomy. Injury to the common peroneal nerve is one of the most common complications of the lithotomy position in open prostatectomy procedures, with 0.3% of patients experiencing a sensory deficit and one in 4,500 patients, a motor deficit [34]. Additional nerves at risk during lithotomy positioning include the femoral nerve, with a one in 50,000 chance of a persistent motor deficit; the obturator nerve, with a 0.5% injury rate; and the sciatic nerve, with a 0.3% to 2% risk of sensory injury and motor involvement in one in 25,000 cases [34,35]. Patients placed in an exaggerated Trendelenburg position also may develop brachial plexus neuropraxia, illustrated by weakness in shoulder adduction and elbow flexion, among other deficits. Deras et al reported a case of severe bilateral forearm rhabdomyolysis after prolonged Trendelenburg positioning with the da Vinci Surgical System in a young, healthy woman [36]. Recently, during 9-month follow-up after robotic prostatectomy, Manny et al reported that 6 of 179 consecutive patients complained of lower extremity neuropathic symptoms with probable injuries to the common peroneal, lateral femoral cutaneous, and obturator nerves [37].

Our institution implements a body-fitting bean bag that functions as a brace for the entire torso when securing the patient. This is to help prevent brachial plexus palsy due to traction caused by slipping in the Trendelenburg position. The patient is placed in the low lithotomy position onto a table equipped with a bean bag, and a gel pad is placed between the patient and the bean bag. The bean bag is taped to the bed but not to the patient, who is further secured from slipping by foam taped across the chest. The shoulders and arms are padded with foam, with the hands and arms in a neutral position and a towel roll in the hands to prevent injury [38,39]. In addition, careful attention to degree of limb extension, the location of placed stirrups/candy canes, padding of bony prominences, and reducing the length of time in the lithotomy position benefits the patient and helps to prevent postoperative neuropathy [35].

3.2.1. Lithotomy position

Patients placed in the lithotomy position not only develop decreased oxygen tension and a significant increase in CO_2 tension, but also an increased cardiac shunt fraction [40,41]. Furthermore, the lithotomy position causes a reduction during systolic blood pressure in the lower extremity to a level comparable to compartment syndrome [42]. There are case reports of the development of compartment syndrome after prolonged duration in the lithotomy position during open prostatectomy. There have also been case reports of rhabdomyolysis with resultant acute renal failure following open prostatectomy with prolonged lithotomy positioning [43,44]. Recently, Galyon et al reported the occurrence of three-limb compartment syndrome during robotic cystoprostatectomy, requiring the patient's need for rehabilitation for 4 months. The patient was placed in the steep Trendelenburg position for 6 hours; the total duration of the procedure was 12 hours. The compartment pressure during this case was abnormally high. The right leg extremity pressure was 60 mmHg, the left leg extremity was 51 mmHg, and left upper extremity was 25-30 mmHg [45]. This is the first reported case of three-limb compartment syndrome after a robotic procedure, and it raises concerns about the risk of neuropathy associated with procedures of this nature.

3.2.2. Pneumoperitoneum

To create pneumoperitoneum, the Veress needle is used. Veress needle placement has its own complications. Azevedo et al studied complications related to insertion of the Veress needle during laparoscopic procedures, and reviewed 38 articles, including 696,502 laparoscopic cases. They found that 1,575 patients were injured by the needle. Eight percent of these injuries involved blood vessels or other hollow structures [46]. This complication also occurs during robotic prostatectomy.

Pneumoperitoneum is used in laparoscopic cases for proper visualization of the surgical field. Pressures are typically in the 12 to 15 mmHg range and CO_2 is the most common gas used, although other inert gases have been studied. Pneumoperitoneum has profound effects on the cardiac, renal, pulmonary, and immune systems. The effects of pneumoperitoneum are attributed to two factors: the IAP itself and CO_2 acting as a drug. There is a need to understand the physiologic effect of CO_2 on various organ systems.

Between 2002 and 2008, Meininger et al published a series of articles on the topic of robotic prostatectomy and cardiopulmonary effects of steep Trendelenburg positioning. They studied the effect of pneumoperitoneum specifically related to robotic prostatectomy [47–50]. In 2002, their initial team experience included a mean operating time of 10 hours as a result of the surgeon's steep learning curve associated with this procedure. The majority of the patient's 10-hour operative time was spent in the steep Trendelenburg position and pneumoperitoneum. Minute ventilation was adjusted according to repeat arterial blood gas (ABG) analysis so as to prevent hypercapnia [48]. A significantly elevated arterial CO_2 pressure even after release of the pneumoperitoneum is attributed to the considerable amounts of CO_2 possibly stored in extravascular compartments of the body that are slowly redistributed and metabolized or exhaled [51]. This combination of steep Trendelenburg positioning and pneumoperitoneum with CO_2 did not affect intraoperative acid base balance or MAP [49]. Meininger et al repeated a similar study in 2004, and found that during 8-hour procedures, CO_2 absorption was more pronounced with extraperitoneal insufflation than intraperitoneal insufflation. The same group conducted another study in 2008 and reached the same conclusion [47,49]. Meininger et al also studied the effect of pulmonary end-expiratory pressure (PEEP) of 5 cmH_2O during robotic prostatectomy and found that it improved arterial oxygenation during prolonged pneumoperitoneum. This practice is common during anesthetic management for robotic prostatectomy at our institution [50].

Recently, Kalmar et al ventilated the lungs in volume control mode with an O_2/air mixture (FIO_2 0.4) and a PEEP of 5 cm H_2O. The tidal volume was adjusted to achieve an arterial-to-end tidal CO_2 ($PE'CO_2$) gradient between 30 and 35 mmHg. The $PE'CO_2$ gradient increased from 7.95 (3.00) mmHg before Trendelenburg positioning to 10.95 (0.039) mmHg after 120 minutes of steep Trendelenburg ($P \leq 0.001$). $PE'CO_2$ and $PaCO_2$ were highly correlated. The correlation coefficients (linear regression) before, during, and after Trendelenburg positioning were 0.68 ($P = 0.0001$), 0.84 ($P = 0.0001$), and 0.58 ($P = 0.002$), respectively [16]. Based on data from the last 4 reviewed studies, hypercarbia during the procedure was not a clinically significant problem in the population studied.

Computed tomographic scanning has shown that up to 56% of patients experience subcutaneous emphysema and that 70% of patients experience pneumoperitoneum after laparoscopic surgery; however, the numbers are unknown for robotic surgery [52]. Typically, subcutaneous emphysema and pneumomediastinum are benign findings; however, postoperative pneumothorax has potential clinical relevance. Pneumothorax has been associated with disruption of the congenital pleuroperiotoneal pathways, as a congenital defect and iatrogenic injury to the diaphragm, and postoperative vomiting [53].

Pneumothorax is diagnosed via decreased breath sounds and/or changes in spirometry and hemodynamic derangement if it manifests into a tension pneumothorax. One case of pneumothorax has been associated with extraperitoneal laparoscopic prostatectomy, where the etiology of the pneumothorax was not defined but thought to be caused by dissection of the musculofascial planes into the mediastinum, causing rupture of the pleural cavities [54]. Routine chest radiography is not indicated after uncomplicated laparoscopic or robotic prostatectomy, as it does not change postoperative patient management after laparoscopic nephrectomies [55].

3.2.3. Trendelenburg positioning

The effect of Trendelenburg positioning on the respiratory system may be the result of cephalad displacement of the diaphragm found in the angle of the 20° to 30° head-down Trendelenburg position used in the OR, thus decreasing pulmonary compliance. The steep Trendelenburg position also has a negative effect on respiratory mechanics, decreasing pulmonary compliance and functional residual capacity [56,57]. Arterial oxygenation is also significantly decreased during Trendelenburg positioning [58]. The effects of lithotomy, steep Trendelenburg positioning, and pneumoperitoneum associated with RALP seem to be additive; however, they are generally well tolerated. The aforementioned study examined the additive effects of pneumoperitoneum and prolonged steep Trendelenburg positioning and reported that hemodynamic and pulmonary parameters remained within an acceptable physiologic range. In addition, CPP and oxygenation were well preserved due to a greater increase in MAP than CVP during the Trendelenburg position [16]. Once the patient is positioned in lithotomy, Trendelenburg position, and pneumoperitoneum has been created, it is very difficult to reposition the patient or bed intraoperatively because the robot is docked to the ports placed in the patient's body. The robot is static and does not move with the patient; major injuries result if unintentional movement occurs. Therefore, to reposition the patient, the robot must be disconnected from the ports in the patient and pulled away from the bedside. During the surgeon's learning curve, when procedure times may be long or unpredictable, ideally agreement should be reached preoperatively regarding whether periodic procedure interruption may be necessary to reposition the patient supine and/or release pneumoperitoneum to restore physiologic norms if necessary.

3.2.4. Pulmonary considerations

There are two ways to ventilate the patient during robotic prostatectomy, either via pressure-controlled or volume-controlled ventilation. Both methods offset the effects of pneumoperitoneum and abnormal positioning to maintain the patient's respiratory mechanics and hemodynamics within a normal range during robotic prostatectomy. Balick-Weber et al investigated the effects of pressure-controlled versus volume-controlled ventilation and showed no hemodynamic benefit of one method over the other during open prostatectomy. However, pressure-controlled ventilation decreased peak airway pressure and increased mean airway pressure during the procedure. Furthermore, patients receiving pressure-controlled ventilation had a significant increase in dynamic compliance when compared with patients receiving volume-controlled ventilation [59].

This study was replicated by Choi et al during robotic prostatectomy. They reported that pressure-controlled ventilation had no advantage over volume-controlled ventilation regarding respiratory mechanics or hemodynamics except for its greater compliance and lower peak airway pressure. In this study, the development of hypoxemia during steep Trendelenburg positioning with pneumoperitoneum was related to the increase of dead space ventilation [60]. Potential air, CO_2, and gas emboli may occur in patients undergoing this procedure, especially in the setting of vascular injury where insufflation pressure may exceed venous pressure. If the embolus is large enough, a decrease in end-tidal CO_2 results. Gas insufflation should be halted and pneumoperitoneum released in patients suffering from gas embolism. After the robot port is removed, patients should be placed in the left lateral decubitus position to help mobilize emboli. If the situation permits, placement of CVP into the right side of the heart to facilitate aspiration of these emboli should be considered.

Hong et al compared venous gas embolisms in robotic versus open prostatectomy and found that the incidence was higher in open radical retropubic prostatectomy (RRP) than in robot-assisted laparoscopic radical prostatectomy. In both groups, there was no significant cardiopulmonary instability; however, anesthesiologists should be especially vigilant during both procedures to avoid potential complications [61]. In a follow-up study, Hong et al provided new information specific to subclinical gas embolisms. They found that these embolisms occurred in 17.1% of laparoscopic radical prostatectomies, and were observed in 7 of 41 (17.1%) patients during the period of transection of the deep dorsal vein complex [62]. In cases of patients with asymptomatic right-to-left shunt and subclinical gas embolism, it is not known if this has a clinically significant sequela in robotic procedures during the steep Trendelenburg position.

3.2.5. Hemodynamic considerations

Normally, additional IV or arterial catheters may be placed intraoperatively if the patient's hemodynamic status requires additional IV fluids, direct pressure monitoring, or ABG samples. However, in robotic prostatectomy, this practice is hindered by the fixation of the robot and torso and the inability to reposition the patient's limbs for access. Therefore, the decision must be made to place IV access and invasive monitoring before the patient is positioned and the robot is docked. Once the patient is properly positioned, the anesthesiologist needs to keep in mind three factors that will affect the hemodynamic and pulmonary status of the patient: Trendelenburg position, lithotomy position, and pneumoperitoneum. These factors account for the majority of physiological changes seen in the robotic prostatectomy patient in addition to the events that develop from surgical intervention. The interaction of these factors is important in the intraoperative management of the prostatectomy patient.

Most patients remain normovolemic; a large series examining the need for transfusion showed that only 0.8% of patients undergoing RALP required blood transfusion [63]. One potential source of surgical bleeding is from the dorsal venous (Santorini's) complex. Other possible sources of major bleeding arise from the inferior epigastric vessels due to injury from port placement and the iliac veins, particularly during lymph node dissection. In the event of uncontrollable bleeding from the dorsal venous complex, temporary pressure may be applied with robotic instruments and insufflation pressure may be elevated until the bleeding is controlled.

In general, the data on estimated blood loss (EBL) is consistent throughout the literature. In a recent review, Lowrance et al compared blood loss between robotic and open prostatectomy and found no study showing less blood loss with the open versus robotic prostatectomy. They demonstrated lower EBL in patients treated with open radical prostatectomy than with RALP [64]. In another review, Ficarra et al analyzed 6 comparative studies and found that open radical prostatectomy (ORP) patients had a relative risk of receiving a blood transfusion that was 4 times higher than for RALP patients ($P = 0.01$) [65]. Bivalacqua et al reported that the reason for less blood loss for robotic versus open prostatectomy included improved visualization due to the positive pressure created by the CO_2 pneumoperitoneum used for insufflation. Pneumoperitoneum reduces the pressure gradient between the blood vessels and the remainder of the operative field, resulting in less venous and capillary bleeding during the operation [66]. Bleeding still occurs, as reported in two patients in our center with aortic injury who were managed without conversion to open procedures; however, this complication is extremely rare [67].

Anesthesiologists should be aware that urine output is not an available intraoperative measure throughout the procedure, as the bladder is opened in the course of the operation to separate the prostate base from the bladder neck. Urine produced by the kidneys after this point drains into the operative field rather than through the catheter. This situation creates a challenge: not only is there no way to reliably measure urine output, but there is an overestimation of blood loss by the mixing of blood and urine in the operative field, which is suctioned for visualization by the surgeon. At our institution, our group prefers limiting IV fluids to approximately one L over the entire procedure. The reason for limiting IV fluids is to reduce soft-tissue edema of the head and neck from positioning and to reduce urine in the operative field to improve visualization for the surgeon in cases of minimal blood loss.

3.2.6. Robotic malfunction

The da Vinci Surgical System consists of a surgeon's console and 3 or 4 robotic arms. One arm serves to control the endoscopic camera, giving the surgeon full stereoscopic vision. The remaining 2 or 3 arms, depending on the model, are used to manipulate the robotic instruments. Although it is rare, robotic malfunction may occur intraoperatively [68]. The da Vinci Surgical System 70 has fail-safe mechanisms that prevent patient injury from malfunctions of the robot alone, including locking in place the patient-side robotic cart when arms are docked to the patient and preventing instrument movement within the patient unless the surgeon is looking through the console while manipulating the instrument effectors. One study showed a robotic failure rate of 2.6% due to malfunction in the set-up joint/camera/arm, power error, monocular monitor loss, metal fatigue, or software incompatibility [69].

Robotic malfunction and clinical outcome may be divided into three categories: patient injury, conversion of the procedure to open form, and/or cancellation of the procedures. These three categories reflect the seriousness of the consequences of robotic malfunction and how the treating team must respond. According to Andonian et al, 168 malfunctions were reported to the FDA for the da Vinci robotic system between 2000 and 2007 [70]. The rate of open conversion due to device malfunction decreased from 94% in 2003 to 16% in 2007. Of the 168 reported device malfunctions, only 9 (4.8%) were associated with patient injury. In the second and third categories, conversion to open procedures and/or cancellation are other complications of device malfunction. According to Kaushik et al, who conducted an international survey in 2010, 100 (56.8%) of the 176 responding surgeons experienced an irrecoverable intraoperative malfunction. Sixty-three respondents experienced mechanical failure before starting urethrovesical anastomosis, of which 26 (41.2%) converted to an open procedure, 20 (31.7%) converted to standard laparoscopy, 10 (15.8%) finished with one less arm, and three (4.7%) aborted the procedure. Thirty-two respondents experienced malfunction before completion of the anastomosis, of which 20 (62.5%) converted to standard laparoscopy and 12 (37.5%) converted to open surgery [71].

There have been differing viewpoints with regard to the issue of robotic malfunction and procedure volume of the center itself. No significant differences existed between surgeons performing a high or low volume of prostatectomies and management of malfunctions. On the other hand, a publication from our institution that surveyed high volume centers found that critical robotic equipment malfunction was extremely rare in institutions that performed high numbers of RALPs, with a nonrecoverable malfunction rate of only 0.4%. Every operative team must have an emergency plan ready if timely undocking of the robot is needed.

4. Postoperative concerns

4.1. Airway management

Prolonged duration in the exaggerated Trendelenburg position may cause airway edema and postoperative respiratory distress in about 0.7% of RALP patients [72]. One case reported a patient who was placed in an exaggerated Trendelenburg position at 45° for 4.5 hours, and who developed postoperative periorbital edema and respiratory distress with stridor due to marked laryngeal edema [73]. The patient's symptoms were caused by venous congestion in the head associated with pneumoperitoneum and the Trendelenburg position. Another case report, of a patient who developed pulmonary edema after a da Vinci-assisted laparoscopic radical prostatectomy, has been published. The exact cause of the pulmonary edema and subsequent reintubation was unclear from the publication, indicating the edema was likely multi-factorial [74]. To prevent postoperative laryngeal edema, Phong et al suggested performing an ETT cuff leak test, as well as maintaining ETT cuff pressure under 30 cmH_20 for patients undergoing prolonged Trendelenburg positioning [74].

4.2. Postoperative pain management

In the case of robotic prostatectomy, there are multiple sources of postoperative pain, including incisional pain, shoulder pain, and visceral pain. Treatment options vary depending on the origin and mechanism of the pain. Patients often complain of postlaparoscopic referred shoulder pain due to residual CO_2 from pneumoperitoneum. One study showed that a continuous intra-abdominal infusion of warm saline (1,000 to 1,500 mL) facilitated expulsion of this CO_2 and significantly reduced the visual analog scale (VAS) scores of postlaparoscopic patients, although this step is not routinely performed [75]. Another study showed that intraoperative use of lower pneumoperitoneum pressures (10 mmHg vs 14 mmHg) resulted in a lower incidence of postlaparoscopic shoulder pain. Patients report decreased pain (using a verbal rating scale) and, on average, require less postoperative opioid 24 hours after surgery when a lower intraoperative pneumoperitoneal pressure is used [76]. Another method of relieving shoulder pain includes placing patients in a 30° Trendelenburg position at the end of surgery and manually inflating their lungs [77]. However, the exact mechanism of postoperative shoulder pain after laparoscopic surgery is still unknown; it is hypothesized that the pain is due to residual CO_2 in the peritoneum causing irritation of the phrenic nerve. The degree of postoperative shoulder pain also has a linear correlation with the size of the CO_2 bubble [78]. Anesthesiologists may decrease this complication by manually decompressing the lungs to expel the CO_2. Subutaneous infusion of local anesthetics has been reported and may provide an alternative treatment when managing post-RALP pain. Sherwinter et al described postlaparoscopic patients who were given a continuous infusion of bupivacaine via the ON-Q® pump delivery system (I-Flow Corp., Lake Forest, CA, USA) and who reported lower VAS scores than those given normal saline [79]. The use of nonstereoidal anti-inflammatorty drugs (NSAIDs) such as ketorolac is a helpful adjunct in the management of postoperative pain, especially during activity. These drugs also help patients return to a full diet sooner and decrease their hospital length of stay after open radical retropubic prostatectomy [80,81]. Other groups have tried to use multimodal approaches as well as pregabalin, which is a gabapentinoid. In addition to celecoxib administered preoperatively, the group showed an intraoperative and postoperative reduction in opioid usage in patients undergoing robot-assisted and laparoscopic prostatectomy [82].

One of the advantages of robotic prostatectomy is the reduced incidence of postoperative pain; however, only two prospective, nonrandomized comparative studies have evaluated postoperative pain after RRP versus RALP. Tewari et al reported a significant reduction in pain scores on POD 1 in those patients treated robotically [83]. Conversely, Webster et al observed a statistically significant difference only in the early postoperative hours, but neither on POD 1 nor POD 14. Although the finding was statistically significant in favor of RALP, the authors reported only a minimal difference in the morphine sulfate-equivalent requirement [84].

4.3. Deep venous thrombosis (DVT)

Even though the majority of perioperative deaths in robot-assisted prostatectomy are caused by pulmonary emboli (PEs), patients have a lower incidence (0.5%) of venous thromboemboli than do those who undergo open prostatectomies (2.5%). For those postlaparoscopic patients (both with and without robotic assistance) who develop symptomatic DVT, thrombi typically occur 5 to 24 days after surgery. Patients with previous DVTs, tobacco use, larger prostate volume, and longer OR time and hospital stay had increased chances of developing postoperative venous thromboembolism (VTE) [85]. In a recent study conducted by Constantinides et al, which examined 995 patients, there were 11 cases of DVT and three cases of fatal PE with open radical prostatectomy [86]. This finding is contrasted with data published by Secin et al, who showed that the incidence of DVT and PE was lower in robotic prostatectomy [85]. Current guidelines for postlaparoscopic patients without any additional risk factors discourage the use of prophylactic treatment other than ambulation. For those patients with VTE risk factors, treatment with a combination of low-molecular-weight heparin, low-dose unfractionated heparin, fondaparinux, intermittent pneumatic compression devices, or graduated compressive stockings is warranted [87].

4.4. Functional recovery regarding impotence, incontinence, and cancer recurrence

The goal for patients undergoing robotic prostatectomy is that they be cured of their cancer and retain continence and erectile function. This goal is termed the "trifecta" [64,88]. Reviewing 37 studies, Ficarra et al reported that laparoscopic retropubic prostatectomy and RRP showed similar continence and potency rates. Only one study using evaluated instruments to measure erectile function [International Index of Erectile function (IEEF) - 5] defined potency as an IEEF - 5 score > 17. Limiting the analysis only to those patients receiving bilateral nerve-sparing robotic prostatectomy with at least one year of follow-up, they found that 49% of ORP and 81% of RALP patients were potent by their definition ($P < 0.001$). Their analysis did adjust for the effects of age, preoperative erectile function, and comorbidity, all of which may have differed greatly between the two groups [65]. This review stated that the literature comparing functional outcomes of RALP and ORP was lacking or inadequate. The few published studies have used insufficient numbers of patients from which to draw definite conclusions on this point; RALP does not seem inferior to ORP with regard to continence and erectile function [65].

5. Conclusion

The majority of patients generally tolerate robotic prostatectomy well and appreciate the benefits; however, anesthesiologists must have an intimate knowledge of the physiological changes associated with RALP. Specifically, anesthesiologists must consider the changes in the cardiopulmonary, ocular, and intracranial systems that occur when patients are placed in the lithotomy and steep Trendelenburg positions, and when pneumoperitoneum is created. Knowledge of these changes may help guide appropriate interventions and prevent perioperative concerns such as ocular complications and nerve injuries, as well as help speed recovery time for patients.

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